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FIELD WORK

AND

INSTRUMENTS.

"The Builder" Students' Series.

FIELD WORK AND INSTRUMENTS.

BY

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PREFACE.

THE following treatise by no means pretends to exhaust the subject, but endeavours to give the student a practical knowledge of the construction and handling of surveying instruments, and to deal with their application in the field for setting out work. The various diagrams which illustrate the subject are made as self-explanatory as possible, in order to avoid the tediousness of continuously turning backwards and forwards, from the diagram to the letter-press. The value of understanding, not only the use, but also the practical construction of an instrument, is shown by the importance set upon this information in the professional examinations, conducted by The Institution of Civil Engineers, The Surveyors' Institution, and The Association of Municipal Engineers and Surveyors, as well as other authorities whose examinations require a knowledge of land surveying and levelling. A practitioner could not be expected to know thoroughly how to deal with a plan, unless he knew how to make it, and those who are most conversant with the instruments employed for the purpose will know best, how either to set about the work themselves expeditiously, or to direct their assistants to do so in the most approved manner. No doubt science owes no little of its advancement to the ingenuity, delicacy, and perfection of the instruments by which its operations are conducted and its investigations carried on — for which the scientific instrument maker is entitled to a larger share of recognition than is usually accorded to him. A manufactory of surveying instruments, is a museum of wonders, to any student who has for the first time the privilege of exploring it, under the direction of a skilled and patient guide. The combination of knowledge, inventiveness, and skill, displayed in the workmanship of these instruments renders a visit to manufacturers' works, not only interesting, but serves to explain many details necessary to know and difficult to describe in writing. In studying the detail of the instruments shown in the following pages, the reader is recommended to do so with the aid of a magnifying glass, as the principal illustrations have been reduced by photography from large size diagrams drawn to scale, which were prepared at various times, during such leisure half hours as the Author could spare from other work. In the descriptive accounts, special attention is directed to the methods usually adopted for testing the accurate working of the instruments described. Unless an instrument is in proper adjustment, the most careful use of that instrument must of necessity fail to secure accuracy.

The Author is indebted to several well-known instrument makers, as well as to previously-published Student's Column articles in *The Builder*, for the illustrations which accompany this work.

A. T. W.

August, 1900.

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FIELD WORK AND INSTRUMENTS.

CHAPTER I.

INTRODUCTION.

THE use of instruments in the field is one of the most delicate operations which fall within the province of a surveyor. It is essential to the execution of reliable work that the surveyor should possess good instruments, most proper for the purpose in view and of the best construction. It is a mistake to suppose that a beginner can work with a second-hand instrument, as the utmost possible circumspection, to avoid the numerous sources of error to which he is liable, demands that the instrument employed should not, in itself, by imperfections, contribute to his anxiety. More especially, as it is impossible to conjecture in what part of the work, after travelling over a long tract of country, his error may lie, if he should find that he has been so unfortunate as to commit any, when such error can only be detected by going over the ground again, or by investigating numerous check angles and lines taken at the time of the original survey. An experienced man, who thoroughly understands the use and adjustment of an instrument, can better employ an inferior instrument than a student whose nervousness leads him to question the result of every adjustment he attempts, and hence the writer emphasises the necessity for the use of instruments by the best makers for the instruction of students.

CHAPTER II.

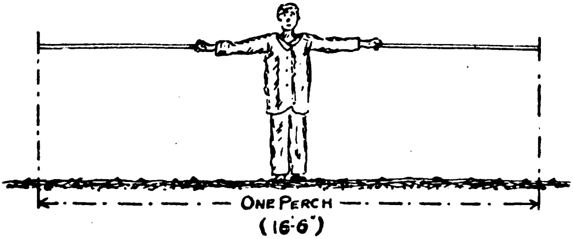
STANDARDS OF MEASUREMENT.

THE human mind requires to be trained by objective teaching in estimating amounts. Thus all our ideas of quantity are comparative and our descriptions of linear measurement relative. The most primitive standards were based upon the human body, thus the "digit" (about $\frac{3}{4}$ in.) was the breadth of the first joint of the forefinger, and the ten fingers of the hand suggested the decimal notation.

A length of about 3 in., or hand-breadth, was called a "palm," and 8 in. was called a "span;" 30 in. formed a "pace," and the height of a tall man, about 6 ft., a "fathom." The length of the French foot, or *pied du roi*, is traditionally supposed to be derived from the length of Charlemagne's foot, and our English foot-measure to have been suggested by the length of the foot of a certain stalwart Saxon chief. The original yard was the gird or girth of a warrior's waist and was adjusted by Henry I. to the full length of his own arm. Even lately, in the country, the Author has seen cloth roughly measured, to arrive at an approximate length by measuring a yard from the tip of the nose with the face turned towards the right, to the extremity of the left hand with the arm held out at full length. An attempt to step an exact yard is found by experience to be more likely to lead to inaccuracy than pacing a known measured distance at the usual rate and pace—an average measure of the length of steps is 24 steps to a chain of 22 yards, or the length of a cricket pitch. A military pace is 30 in. In cavalry regiments, the average distance paced by a horse is tested and chronicled, and horses' paces are often taken as units for measurements of distances in the execution of a military survey. An ordinary horse will cover about three yards of ground every time the rider rises in the saddle when at a trot. In cantering, each time the leading foot touches the ground is reckoned as a canter, and a scale to suit the average distance covered at each canter, is constructed.

In a manuscript of the thirteenth century the following reference to ancient modes of a survey is made: "The seneschal ought, at his first coming, to cause all the demesne lands to be *measured* by true men, and he ought to know by the *perch of the country* how many acres there are in each field, and he must cause all the meadows and several pastures to be measured by *acres*."

At a very early period, land in country districts was probably measured into perches and acres by ploughmen only; thus a ploughman would stand with an ox-goad in each hand extended, and the distance (from the end of one goad to the end of the other) indicated, in a rough manner, one perch.



But the length of one perch varied in some parts of the country, although in very remote times the measure of 5½ yards to the perch, as still used for the statute pole or perch, appears to have been usual; and another thirteenth-century writer has stated that "an acre ought to be 40 perches long and 4 perches wide, and the king's perch is 16½ ft.; then an acre is 66 ft. in width; be it known that 24 furlongs are a league" (3 miles).

Now, at that period it was necessary, especially upon lands near to the borders of the counties of Cheshire and Lancashire, where different systems of measurement existed, that the length of the perch should be accurately defined in all transactions relating to land tenure, because, as stated in the manuscript last referred to, acres are not all of one measure, for in Devonshire they measured the perch at 15 ft.; in Somersetshire, 15 ft.; in Cornwall, 18 ft.; in Lancashire, 21 ft.; in Staffordshire and Cheshire, 24 ft. The reason why Cheshire, Lancashire, statute and other acres and perches were not all alike is not certainly known; but it may have been because the ploughmen of certain districts were taller men than others, and were able to take a longer reach with the poles or goads; or, possibly, because the length of the goads varied in different parts of England.

Among early units, the Chaldean mile was equal to 4,000 steps of a camel, and the Olympian racecourse gave to the Greeks their unit, the stadium.

The old London mile is based upon the Roman measure of one thousand paces (*millia passuum*) with each foot, and the league upon a fair hour's walk. The French and German leagues were also described in a simple way. The Norwegian mile was based upon an hour's drive, and Dutch boatmen are said to have measured distances by the time occupied in steadily smoking a pipe. Thus a variety of units was obtained, and hence the difference of measurement practised not only in different countries but in different parts of the same country. Agricultural property was in consequence greatly affected thereby.

Deal rods have been employed for measurement, but are found liable to change from atmospheric influences. The variation is, however, reduced when the rods are saturated with boiling oil, and afterwards covered with a thick varnish. To protect the ends, metal caps are added. Glass rods have also been used, their extremities being fitted with bell-metal caps connected to the rods by springs. Hollow glass rods have proved less liable to sudden and irregular changes than solid brass rods. Iron and steel chains commend themselves from their portability. Great accuracy has been obtained with the use of a steel chain properly levelled, pulled regularly, and employed at a uniform temperature. The two lengths most generally employed are 66 ft. and 100 ft., each divided into 100 links from outside to outside of handles.

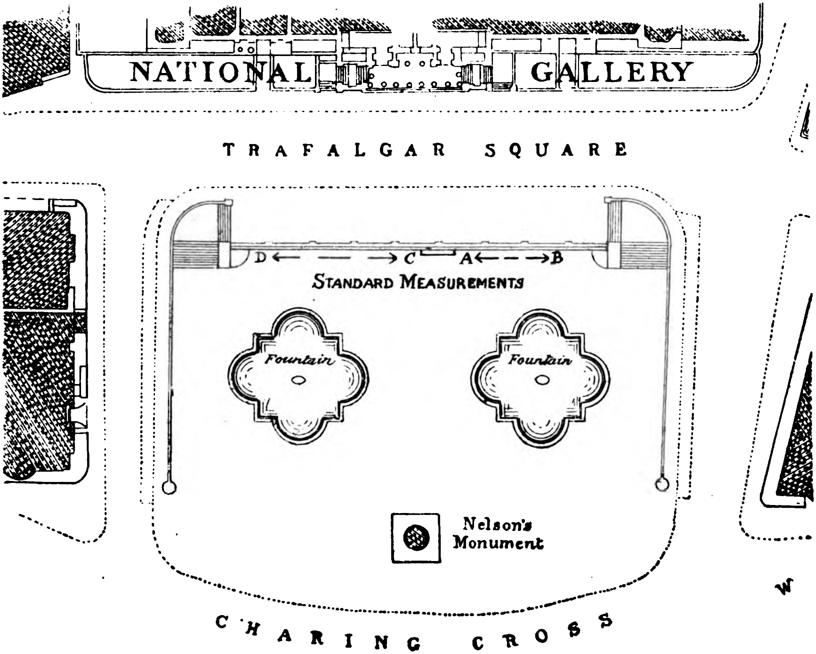
In Edward I.'s reign the statute acre was fixed at 160 square poles or perches. Hence, with the use of Gunter's chain, ten square chains equal one acre. When the 100-ft. chain is employed, the number of square chains has to be divided by $\frac{10000}{43560}$, or multiplied by its reciprocal ·2295 to arrive at the acreage. Hence it will be seen that when acreage is required, a considerable portion of the arithmetical work is saved with the use of Gunter's measurements. Having arrived at the area in square links, cut off five figures to the right-hand, and the figures to the left-hand will then express acres. To obtain roods and perches of the decimal portion of an acre indicated by the figures upon the right hand of the decimal point, multiply first by 4 and then by 40.

The Act of Parliament, 5th Geo. IV., c. 74 (1824), declared that a certain metallic bar made by Bird in 1760 shall, when at a temperature of 62° Fahr., be considered the standard yard of the British Empire. Without further reference to its origin, and in order to provide against its loss, injury or destruction, the same Act declared that the length of a pendulum vibrating seconds of mean time in the latitude of London, at the level of the sea, measures 39·1393 in. with the same length of inch as the yard of 36 in., so that the yard is in the fixed proportion thereto of 36 to 39·13929. The standard of 1760 was actually destroyed about ten years after the passing of the above-named Act by the burning of the Houses of Parliament, and, consequently, the construction of another standard became necessary. The Government wisely determined to make this an opportunity to thoroughly revise the whole subject of standards of measure and of weight for the British Empire. Some doubt was thrown upon the accuracy of record of a pendulum, and finally a Standards' Committee, composed of eminent mathematicians, with the late Sir G. B. Airy, Astronomer-Royal, at its head, voluntarily made various comparisons over a period of eleven years, during which more than 200,000 micrometer readings, with the use of special thermometers, were made. They decided that the length of one yard be the standard unit of length, and that a line standard was preferable to an end standard, *i.e.*, that the distance between two lines marked upon a bar is preferable to that from end to end of a bar. Also that the standard be made of an alloy composed of copper 16 parts, tin 2½ parts, zinc 1 part—a composition now known as Bailey's metal. The Act 41 and 42 Vict., c. 49, entitled an Act to consolidate the law relating to Weights and Measures, 1878, states that the imperial yard shall be the only unit or standard measure of extension from which all other measures of extension, whether lineal, superficial, or solid, shall be ascertained.

The great feature in a surveyor's chain is that it is decimally divided. At every tenth link from each end of a chain a piece of brass with notches or points is fixed to denote the number of the tens, varying in number according to position from the nearest end of the chain, that at 10 links having one notch or point; at 20, two; at 30, three; and at 40, four points. At 50, or the centre of the chain, is a round plain piece of brass. The chain being thus marked the links may be easily counted from either end, the tellers at 90, 80, &c., being respectively the same as that at 10, 20, &c., so that it is immaterial which end of the chain is placed at the zero point. To guide the eye in counting the number of intermediate links, some chains have also a small brass ring midway between each tenth index, to show the fifth link, and thus facilitate the reading of the unit measurements. Part of the first link at each end is made into a large ring or handle for holding the chain in the hand. The best chains have the links connected by three unwelded elliptical rings, by which means the chain is rendered very flexible, and the links are not so liable to twist or coil when the chain is folded up. Oval-shaped rings are far preferable to round rings uniting the links of a chain.

The décametre chain consists also of 100 links, each of which measures one décametre. The length of a metre being 3·28 ft. or 39·37 in., each link is only 3·93 in. long, or about half the length of one of Gunter's chain links, and the total length of the chain is only 32·8 ft. Its short length is an argument against its use, to overcome which a chain of this description is often made two décametres in length, and each link 0·656 ft. from centre to centre of the connecting ring, tallied at every two metres.

Chains when new, ought always to be examined to see if they are of correct length. They also elongate with frequent use, and need to be afterwards occasionally tested. Special standards for the use of surveyors in London have been fixed by the Government upon the north side of Trafalgar-square (see illustration), and also in the Guildhall. Their lengths are derived from the British standard yard, which is the distance at the temperature of 62° Fahrenheit between two marks upon a certain bar, which is preserved in the office of Her Majesty's Exchequer, official copies being kept at the Royal Mint, the Royal Observatory at Greenwich, and in the rooms of the Royal Society.



The standards above alluded to for testing chain measurements in London are fixed as permanent bronze marks let flush into the granite plinth of the terrace wall in front of the National Gallery, London. Permanent standards have likewise been fixed by various municipal authorities in prominent positions over different parts of the country. The correct length of a chain should be that from out to out, that is from the outside of the handle at one end to the outside of the handle at the other end. If the chain be found to have stretched only slightly, say, half an inch, it can be rectified with a hammer by closing the open joint in several rings which unite the straight links of iron or steel wire, or by tapping the eyes at the end of the links. If, however, the stretch, as is frequently the case, be from one to two inches, it will be necessary to take out some of the connecting rings in such a manner as to keep every division of ten links in its proper place upon the standard. The error, however slight, which may exist in a chain's length will be very dangerous if the main lines of a survey be measured with it. Any inaccuracy in the length of a base line will inevitably distort the whole survey by altering the relative positions of other objects shown upon the plan.

Chain tapes or steel bands are extensively employed where accurate measurements are important. They are usually made $\frac{3}{8}$ in., $\frac{1}{2}$ in., $\frac{5}{8}$ in., and $\frac{3}{4}$ in., etched feet and links. Some tapes are etched feet and inches. Some have both these subdivisions. They are made to wind upon an **X** reel or in a metal case. The American type consists of narrow bands of steel ribbon $\frac{1}{8}$ in. wide, made in lengths of 33 to 1,000 ft., either with or without joints. Graduations are marked by riveting a small brass sleeve to the tape. It is found that a 100 ft. tape expands for each 10° one inch in 1,400 ft., so that the expansion for each running foot for one degree is ·000072 of an inch.

Linen tapes become longer or shorter than their stated lengths, according as they are used in wet or dry weather, while steel tapes are liable to kink and twist, and there are few persons who can repair them except their makers.

Casella's patent Ordnance tape-box is made in a specially substantial manner to withstand hard usage, and has the following advantages, viz. :—The spindle is provided with a slit, by means of which a new tape, or, if needs be, the end of the broken tape, can be secured immediately, *without the use of a needle and thread.* To effect this, unwind any tape that may be left in the box; then prevent the nut from turning, by pressing against it with the palm of the left hand; unscrew the spindle, and remove the end of the tape ; insert the new tape in the slit; double it a little at the end, and place a small strip of wood in the loop thus formed; replace the spindle, and screw it up tightly. There is no small screw to get loose and fall out, and no screw-driver is required. The box itself is made of solid leather only, without paper lining, and is thus well calculated to withstand wet weather. The brass lining of the tape opening and the rollers are very substantial, and are secured firmly to the box by through-rivets. An ordinary tape box will last out several tapes. To insert a new one unscrew the winding knob, and take the tape out of the box through the aperture in the centre. It is a good plan to have the first four feet of a linen tape bound upon the back with strong leather, as this end of the tape is most subject to wear and tear. Generally speaking, it is found with metallic tapes that the wire causes the surface to wear more rapidly than in the case of linen tapes in which no wire is inserted.

CHAPTER III.

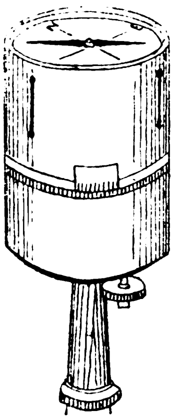
THE CROSS STAFF.

THE cross staff is an instrument used for setting out lines at right angles to a given line, and consists in its simplest form of a rod, having a spike at its lower end for fixing into the ground, and two pairs of sights attached at right angles to one another at its upper end. Sometimes these sights are made with hinged joints to fold down, and at other times two fine grooves are sawn at right angles to one another, through a block of wood, which forms the head of the instrument.

Fig. 1 (pages 13–15) shows a cross staff head with brass fittings. The supporting rod which connects it to the ground is set up and fixed plumb over the point at which the right angles are required to be set out. The head consists of an octagonal brass box having slots in four of its sides, two of each being in line with one another through the centre of the instrument, and so cut that a broad opening comes horizontally exactly opposite a small circular opening, the latter serving as an eye-piece. In the centre of each of the broad openings shown below A and above D in fig. 1 are fixed wires or horse-hairs, which are intended to range the eye in adjusting the instrument over the rod upon the main line, and to act as a guide in setting out the cross line. Narrow openings with a small circular hole at top and bottom are provided opposite one another in each of the four remaining sides of the octagon, as shown between A and D in fig. 1. On the top of the cross staff head is shown a compass box, which can be revolved round by the hand, while the lower octagonal portion remains fixed. By means of this compass, the magnetic meridian can be obtained with reference to any required direction. This is accomplished by setting the points on the compass box, marked north and south, as near as possible in the direction of the line under observation, and allowing the needle to float freely on its agate centre; then when the needle is at rest, the angle which the magnetic meridian makes with the given line can be read off the graduated ring, which is marked round the edge of the compass box. By means of a small catch or trigger in the side of the box, situated in the rim where the word "compass" is marked in our illustration (page 13), the needle can be thrown off its bearing when not in use.

The needle, however, is scarcely long enough in this instrument to indicate more than the general direction of the north.

The cross staff is sometimes constructed in a circular form instead of the octagonal shape shown in fig. 1, and may be fitted with a rack and vernier, in addition to the compass box, as shown in the accompanying illustration. When this is done the upper portion is made to revolve upon the centre of the box over a graduated circle fixed upon the circumference of the instrument, so that when great accuracy is not of importance, any angle may be thus set out approximately. A special form of head to a cross staff is sometimes made in the shape of a sphere with curved slots upon its surface, arranged opposite one another, so as to facilitate the setting-out of a right angle when the ground is not level. With the use of the vertical shape indicated in fig. 1 the ground should be moderately level.



The accuracy of an ordinary cross staff may be tested as shown in figs. 2 and 3, where A B C D represents an enlarged sectional plan of the instrument shown in fig. 1. Having set up the cross staff vertically over the point E by means of the rod, which is fixed plumb in the ground, the eye is applied to the small opening at A, and ranged by the vertical hair or wire in the broad slot at C; the pole H is fixed at any convenient distance in the direction of the line of sight A C. Then, without moving the cross staff the eye is applied at the small opening at B, and ranged by the vertical

hair or wire in the broad slot at D; the pole F is fixed in the ground in the direction of the line of sight B D, which should be at right angles to the direction A C. Having done this, we next turn the cross staff round a quarter of a circle, so that when half reversed the position indicated by the letters on fig. 2 take the position shown in fig. 3. If when the line of sight A C points towards F, and the line of sight D B points towards H, the poles F and H, as set out in fig. 2, still remain, when viewed in fig. 3 in the lines of sight A C and D B respectively, the instrument is correct. If not, it should be returned to the makers for adjustment.

The cross staff is used for setting off perpendiculars from a base line that are too long to be approximately estimated by the usual tape or off-set rod measurements, also for laying out streets and building lots, and for setting out lines of cross-sections at right angles to a longitudinal direction, preparatory to taking levels. In the latter case the instrument commends itself as being sufficiently simple for a sharp intelligent chainman to be trusted to assist the surveyor in setting out his transverse sections, as all he has to do is to set two opposite sights in the direction of the given line, whereas an optical square or a box sextant, as will appear by the subsequent description of these instruments, could only be used for this purpose either by the surveyor himself or a competent assistant.

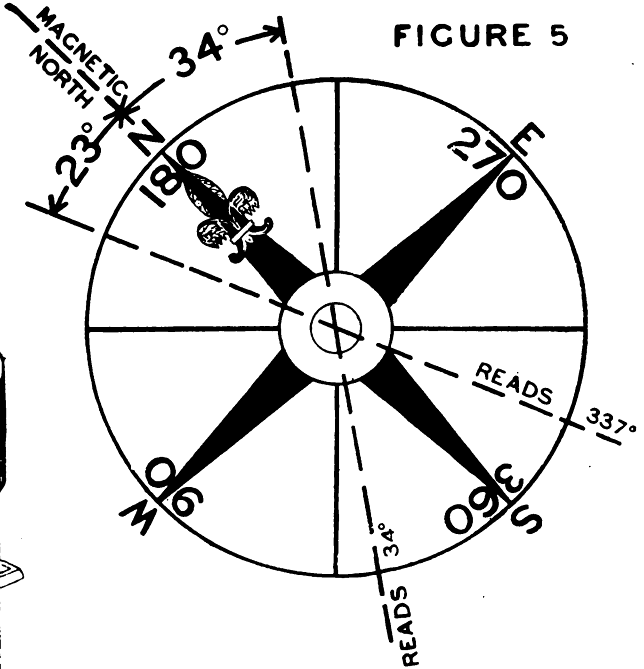
OMPASS

PATTERN —

[*Field Work and Instruments*, *pp.* 13, 14, 15.

PLAN OF FLOATING CARD

FIGURE 5



$$360^\circ - 337^\circ = 23^\circ$$

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NED HORIZONTALLY IN THE HAND UNTIL THE VERTICAL SIGHT
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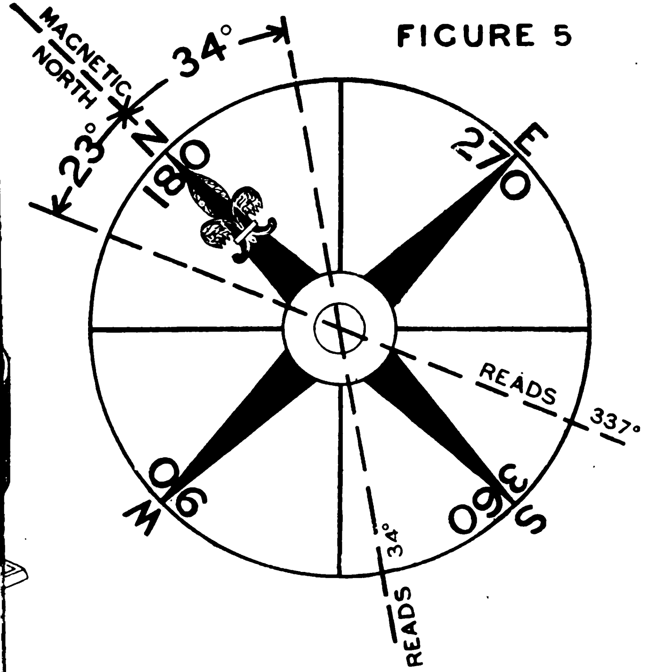

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CHAPTER IV.

THE PRISMATIC COMPASS.

THE prismatic compass is, as its name denotes, an instrument for measuring angles with reference to the magnetic meridian. It is shown in fig. 4 (pages 13–15) open ready for use, consisting of a glass-covered box containing a magnetic needle, which turns upon an agate centre. The needle, which is at least 4 in. in length, and therefore capable of providing greater accuracy than can be obtained with the use of the shorter needle as indicated in fig. 1, attached to a cross staff, is in a prismatic compass either attached to a card, as shown, or to a light graduated silver ring, which revolves with it. The ring or card has its outer edge graduated into degrees and half degrees, sometimes subdivided into 20 min. or thirds of a degree. That known as Major Hutchinson's pattern constitutes the Woolwich and Sandhurst instrument, and consists usually of a box about 2¾ in. diameter. When packed in a leather sling case it is very portable, and largely used in military surveying.

A magnifying prism, situated between A and B in fig. 4, is attached to one side of the box, and made to slide up and down in a groove, so as to obtain a proper focus for reading the divisions distinctly upon the circle underneath. Upon the opposite side is attached a vane having a fine thread marked C down its centre. This vane is equal in height to the diameter of the box, and has a hinged joint so as to turn down flat upon the glass, or upon the fixed cover plate over the glass. This cover is indicated in fig. 4 by only a portion of the card being seen. When turned down this vane lifts the card off its bearing, and the needle ceases to act. When turned up, as shown in fig. 4, the needle is free to turn, and the instrument must be held horizontally so that the card may play freely on its centre, otherwise the results obtained will not be accurate. The sliding framework by which the prism at B can be raised or lowered for arranging the focus is also connected by a hinged joint so as to fold back and to be easily packed in the case when not in use. In order to show bearings in degrees to the east of north, the card is graduated from the south, reading west, as shown in fig. 5. The numbers also are inverted upon the card, so that whilst the eye is looking directly at an object through the sight vane the figures may be refracted in an upright position through the prism of glass while viewing the direction required. The vibrations of the compass card, when playing freely, can be checked by gently pressing a small spring, not shown in the illustration, but generally placed in the side of the box under the sight vane C, and below the level of the floating card. The more sensitive the magnet the more liable is it to swing about. When the compass is held over a station point or any selected point in a line, and an object is viewed through the hole and slit in the prism at B, the instrument is turned horizontally by the hand until the fine thread in the vertical vane at C bisects the point under observation. The perpendicular thread of the sight vane C and the divisions upon the card appear to be coincident when viewed through the prism. When the card is at rest the number of degrees indicated in the line of sight is read through the prism. If under certain circumstances an increased amount of light should be found necessary in order to read the figures correctly, the card can be clamped while at rest, and the instrument tilted up a little above or below the horizontal, until there is sufficient light upon the card to see the divisions distinctly.

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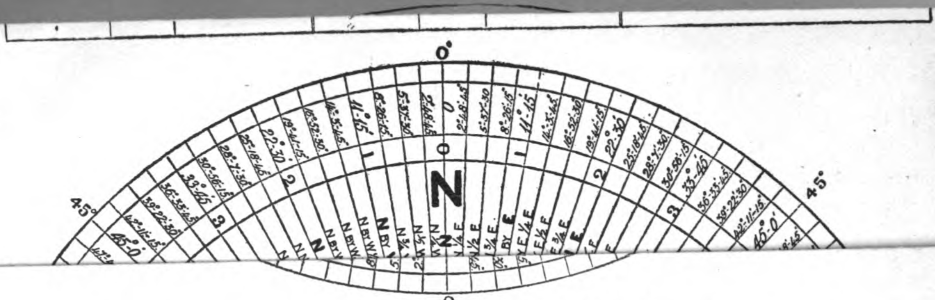
In the western hemisphere in the year 1880 there was little or no variation upon a line drawn through the west coast of Hudson's Bay, the east coast of Lake Superior in North America, the west coast of Lake Erie, between Canada and the United States, thence passing through Washington and Charleston, Puerto Rico among the West Indian islands, and between Barbadoes and Trinidad, to the north-east coast of South America, crossing that continent to the south Atlantic Ocean at San Paulo. To the west of this neutral line the magnetic curves increase

uments, pp. 20, 21, 22.



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RULES TO CORRECT THE COMPASS FOR VARIATION.

Course by Compass Given.	True Course Given.
Allow Easterly variation to right hand.	Allow Easterly variation to left hand.
Allow Westerly variation to left hand.	Allow Westerly variation to right hand.
Will give True Course.	*Will give Magnetic Course.*

CHAPTER III.

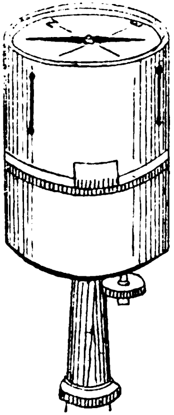
THE CROSS STAFF.

THE cross staff is an instrument used for setting out lines at right angles to a given line, and consists in its simplest form of a rod, having a spike at its lower end for fixing into the ground, and two pairs of sights attached at right angles to one another at its upper end. Sometimes these sights are made with hinged joints to fold down, and at other times two fine grooves are sawn at right angles to one another, through a block of wood, which forms the head of the instrument.

Fig. 1 (pages 13–15) shows a cross staff head with brass fittings. The supporting rod which connects it to the ground is set up and fixed plumb over the point at which the right angles are required to be set out. The head consists of an octagonal brass box having slots in four of its sides, two of each being in line with one another through the centre of the instrument, and so cut that a broad opening comes horizontally exactly opposite a small circular opening, the latter serving as an eye-piece. In the centre of each of the broad openings shown below A and above D in fig. 1 are fixed wires or horse-hairs, which are intended to range the eye in adjusting the instrument over the rod upon the main line, and to act as a guide in setting out the cross line. Narrow openings with a small circular hole at top and bottom are provided opposite one another in each of the four remaining sides of the octagon, as shown between A and D in fig. 1. On the top of the cross staff head is shown a compass box, which can be revolved round by the hand, while the lower octagonal portion remains fixed. By means of this compass, the magnetic meridian can be obtained with reference to any required direction. This is accomplished by setting the points on the compass box, marked north and south, as near as possible in the direction of the line under observation, and allowing the needle to float freely on its agate centre; then when the needle is at rest, the angle which the magnetic meridian makes with the given line can be read off the graduated ring, which is marked round the edge of the compass box. By means of a small catch or trigger in the side of the box, situated in the rim where the word "compass" is marked in our illustration (page 13), the needle can be thrown off its bearing when not in use.

The needle, however, is scarcely long enough in this instrument to indicate more than the general direction of the north.

The cross staff is sometimes constructed in a circular form instead of the octagonal shape shown in fig. 1, and may be fitted with a rack and vernier, in addition to the compass box, as shown in the accompanying illustration. When this is done the upper portion is made to revolve upon the centre of the box over a graduated circle fixed upon the circumference of the instrument, so that when great accuracy is not of importance, any angle may be thus set out approximately. A special form of head to a cross staff is sometimes made in the shape of a sphere with curved slots upon its surface, arranged opposite one another, so as to facilitate the setting-out of a right angle when the ground is not level. With the use of the vertical shape indicated in fig. 1 the ground should be moderately level.



The accuracy of an ordinary cross staff may be tested as shown in figs. 2 and 3, where A B C D represents an enlarged sectional plan of the instrument shown in fig. 1. Having set up the cross staff vertically over the point E by means of the rod, which is fixed plumb in the ground, the eye is applied to the small opening at A, and ranged by the vertical hair or wire in the broad slot at C; the pole H is fixed at any convenient distance in the direction of the line of sight A C. Then, without moving the cross staff the eye is applied at the small opening at B, and ranged by the vertical

hair or wire in the broad slot at D; the pole F is fixed in the ground in the direction of the line of sight B D, which should be at right angles to the direction A C. Having done this, we next turn the cross staff round a quarter of a circle, so that when half reversed the position indicated by the letters on fig. 2 take the position shown in fig. 3. If when the line of sight A C points towards F, and the line of sight D B points towards H, the poles F and H, as set out in fig. 2, still remain, when viewed in fig. 3 in the lines of sight A C and D B respectively, the instrument is correct. If not, it should be returned to the makers for adjustment.

The cross staff is used for setting off perpendiculars from a base line that are too long to be approximately estimated by the usual tape or off-set rod measurements, also for laying out streets and building lots, and for setting out lines of cross-sections at right angles to a longitudinal direction, preparatory to taking levels. In the latter case the instrument commends itself as being sufficiently simple for a sharp intelligent chainman to be trusted to assist the surveyor in setting out his transverse sections, as all he has to do is to set two opposite sights in the direction of the given line, whereas an optical square or a box sextant, as will appear by the subsequent description of these instruments, could only be used for this purpose either by the surveyor himself or a competent assistant.

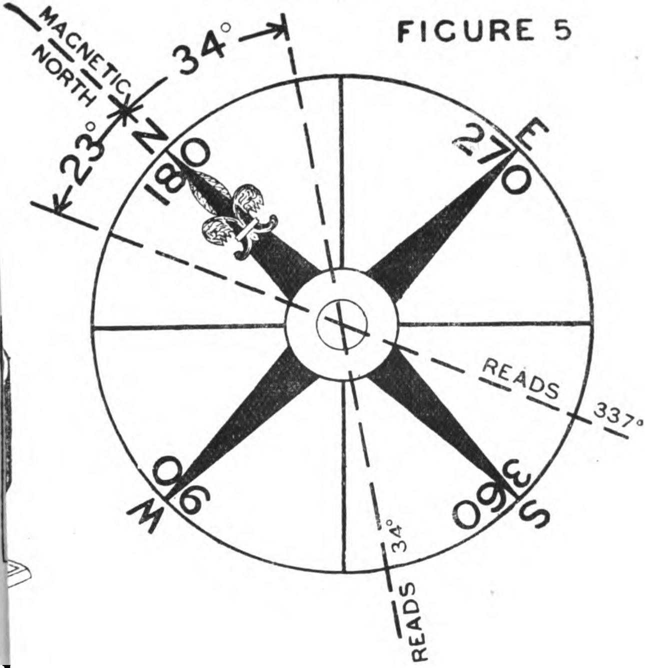
OMPASS

[*Field Work and Instruments,*
pp. 13, 14, 15.

PATTERN ——

PLAN OF FLOATING CARD

FIGURE 5



$$360^\circ - 337^\circ = 23^\circ$$

HELD IN THE DIRECTION OF A GIVEN LINE, THE BEARING OF
VED HORIZONTALLY IN THE HAND UNTIL THE VERTICAL SIGHT
ECTION OF THE GIVEN LINE. THE FLOATING CARD IS ALLOWED
ESSING THE SPRING STOP SITUATED BELOW **C**.
AT **A**, IS THEN READ THROUGH THE PRISM OF GLASS AT **B**.
IE ZERO OR 360° CORRESPONDS WITH THE SOUTH POLE IN THE
IDE, 270° ON THE EAST SIDE, AND 180° DENOTES THE NORTH;
THE MAGNETIC NORTH, WILL LIE TO THE LEFT HAND SIDE
AN 180°, AND TO THE RIGHT HAND SIDE OF THE SURVEYOR,
DIRECTION OF THE MAGNETIC MERIDIAN, WILL BE IN A
IE POINT OF VISION, EQUAL TO THE NUMBER OF DEGREES
HAN 180°; BUT IF THIS RESULT EXCEEDS 180°, THE ANGLE
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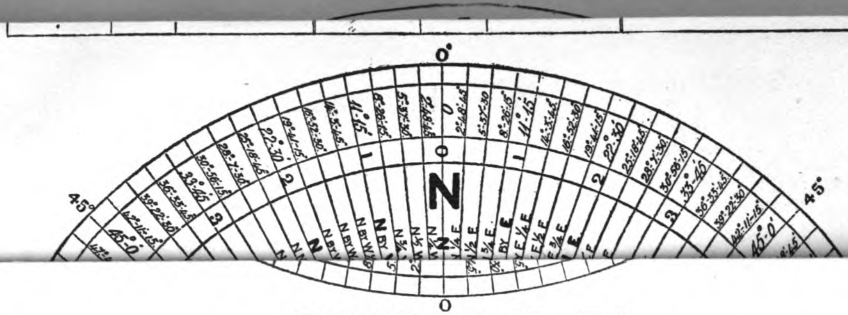
uments, pp. 20, 21, 22.



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Allow Westerly variation to left hand.	Allow Westerly variation to right hand.
Will give True Course.	*Will give Magnetic Course.*

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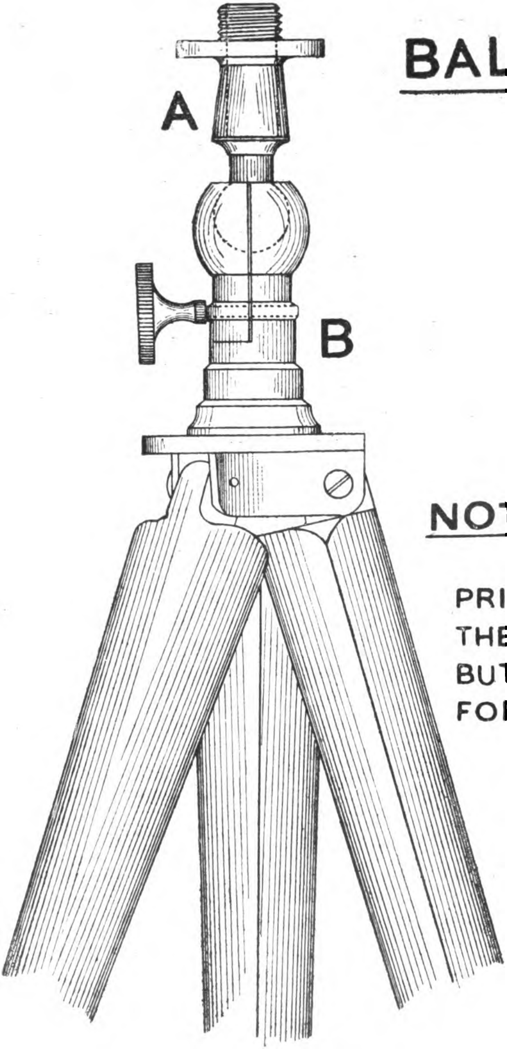
eastward in variation being 10° E. at the Fiji Islands, decreasing thence towards zero at a point in the mid-Pacific Ocean. It increases also to 23° E. to Vancouver's Island, decreasing to a line of no variation along the China coast. To the east of this line in the western hemisphere the magnetic curves increase westward in variation, being 13° W. at Montreal and at Pernambuco, and about 3° E. at Jamaica.

These angles of deviation from the true or astronomical meridian are continually varying. At Greenwich in the year 1576 the magnetic variation was 11° 15′ E.; and between 1657–62 there was no variation. In 1820 it was about 24° 11′ W. The needle is also subject to diurnal fluctuations, the north end being drawn most to the west at about 2 p.m., and most to the east during the night or early morning. The amounts, however, are inconsiderable, except when magnetic storms occur, which produce great disturbances.

A rough approximation to the direction of the true meridian for finding one's way by the aid of a map which has its side margins true north and south, or with its north point clearly defined, is to hold a watch with its face level and with the hour hand directed towards the sun. Then an imaginary line drawn from the centre of the dial to bisect the lesser of the two spaces or angles between the hour hand and the fig. xii. will be the direction of the meridian or south in the northern hemisphere within about 20°. This simple expedient (says Colonel Richards, Professor of Military Topography) enables a horseman to hold a map nearly north and south without dismounting, and it is also useful to a land surveyor on foot.

In fig. 5 of the illustration (pages 13-15) two positions of the needle are indicated, one direction reading 34° and the other 337°. The difference between these two azimuths would express the angle taken in the direction of the hands of a watch, which the objects viewed would subtend at the point of vision. An azimuth exceeding 180° denotes that the direction of the object to which it is measured lies to the left of the direction from which azimuths are usually measured. For practical purposes a surveyor may express

FIGURE I



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[*Field Work and Instruments, pp.* 24, 25.

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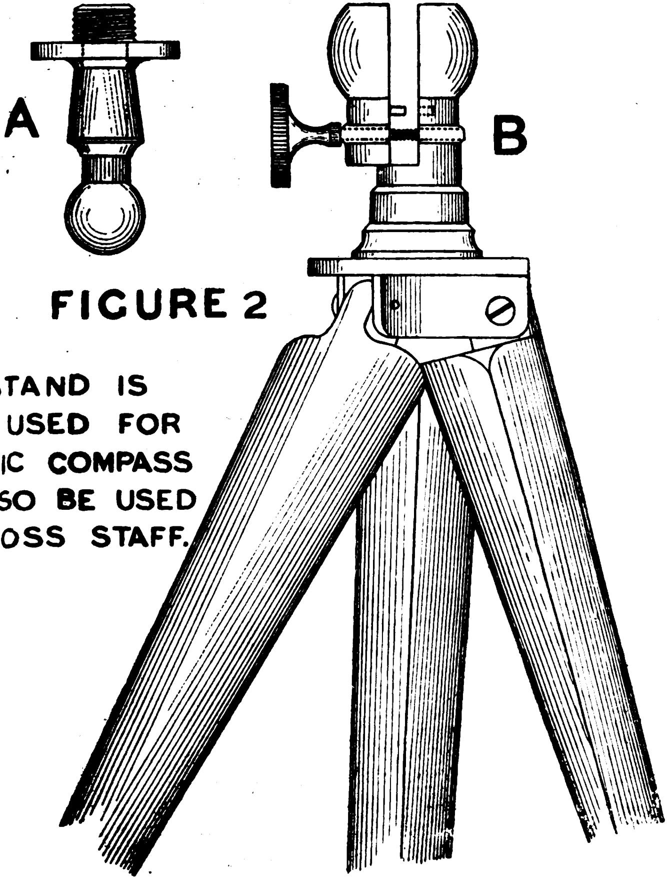

FIGURE 2

TAND IS
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SO BE USED
OSS STAFF.

these two directions as being in one case 34° E., and in the other case 23° W., of the magnetic meridian, the excess of 360°, above the angle read, being taken when that angle is greater than 180°.

The prismatic compass is generally made as shown in fig. 4 (page 14), with a fixed cover to protect its face, having an aperture with stout glass let in for reading the card, and it is, in this form, arranged to be held in the hand for sake of portability, but it can also be made of larger diameter with an uncovered glass top, as shown in fig. 3 of the annexed illustration, and constructed to fit on to a ball-and-socket stand, the details of which will be clear upon reference to figs. 1 and 2 (pages 24, 25.) Fig. 2 shows the parts which are fixed together in fig. 1 to form a tripod, the legs of which are so constructed that when shut up they form one round staff, secured in this convenient shape for carriage by one or more brass rings which are easily slipped over the foot of the staff and pulled up its tapering diameter until they bind the three legs together. The ball-and-socket type of adjustment sufficed until Sisson introduced the adjustment by four screws, uniting parallel plates, the result being that the centres of adjustment of these screws could be fixed at a greater distance from the vertical axis of the tripod than in a ball and socket adjustment. Three connecting screws were subsequently substituted by other operators for four screws and radiating arms added to the connexions with the centre for still increasing the radius measured from the vertical axis, and thus improving the delicacy of the parallel

Fig 3

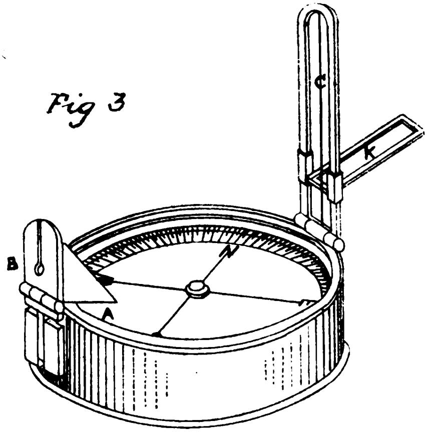


plate adjustment. Ramsden also introduced a tangent screw and clamp, the action of which for traversing small distances will be explained when dealing with the Theodolite.

When the prismatic compass is, by the means above described, set up, horizontal angles can be measured from the magnetic meridian upon level ground with sufficient accuracy for filling in the minor portions of a survey. Having determined the bearings of the two objects, *i.e.*, the angles they make respectively with the magnetic meridian, the difference between these two readings gives the angle at the observer's eye between the direction of two given objects. Thus, in military surveying the draughtsman is provided with a sheet of survey paper having parallel east and west lines engraved upon it, and any unknown point is chiefly determined by interpolation, or taking the angles to two known points, and protracting the opposite angles from these points. It should be borne in mind that the presence of iron, whether in the shape of heavy keys or of an iron chain lying along the ground or the vicinity of an iron bridge, may exercise an influence over the observed bearings to a very important extent. Sometimes a mirror, marked K in fig. 3, is supplied with a prismatic compass, and is intended for the purpose of reflecting objects above or below the level of the observer. The mirror can be placed with its face upwards or downwards, and can be removed at pleasure. It is made to slide up and down with sufficient friction to remain at any part of the back of the vane C that may be required. When the instrument is used for observing the azimuth of the sun, a dark glass or glasses must be interposed over the prism, the joint upon which they act permitting them to be turned down over the sloping side of the prism box.

The marked end of the needle points to the magnetic north, and when the north point is plotted upon a plan, the fleur-de-lis invariably is drawn to point towards the north, so that the barb or back part of the arrow points towards the south. As the true north never varies, we have by its means a constant direction to which to refer the relative position of all objects. When plotting the north point, it must be remembered that as the magnetic meridian is in England at present west of the astronomical meridian, the true north must, in this case, be drawn east of the magnetic north after the magnetic north has been plotted off one of the base lines connected with the survey. An ordinary protractor, as usually found in a box of drawing instruments, is quite sufficient for this purpose, as the direction after all needs to be only approximately determined.

CHAPTER V.

THE CLINOMETER.

THE clinometer is a portable instrument for measuring inclinations of slopes, or even for tracing a horizontal contour line through a district; but as it is carried in the hand, and is therefore susceptible of any sudden irregular movement of the operator, and is also liable to be disturbed by wind, great care is required in its use, and the results arrived at by it are necessarily only approximately true.

Various instruments have been made for determining the inclination of a regular slope, such as is presented by the batter of a roof, the inclination of a hand rail to steps, or the slope of an embankment. A piece of hard board cut in a semicircular shape with a graduated edge upon its curved side, having a plummet suspended by a cord from its centre, is often used as a simple and effective method. The board is made of from 3 to 6-in. radius, and is held vertically with its straight edge uppermost. The surveyor's eye is directed along the straight edge or diameter of the board, which is thus placed to suit the direction of any given slope, and the number of divisions read off the crossing of the vertical line of the suspended cord will then show, by comparison with the reading furnished when the straight edge was held in a horizontal direction, the amount of deviation from the horizontal. This may be expressed either as the rise of a certain amount in a stated distance, or as an angle of inclination. The accuracy of such observation can further be greatly aided by the addition of sight-vanes, fixed at each end of the straight edge forming the diameter of the instrument, or by attaching an independent and long straight edge accurately to the straight edge contained within the semicircle.

Figs. 4 to 6 illustrate a combined prismatic compass and clinometer, the former to record horizontal angles, the latter to record vertical angles. Fig. 4 shows a plan of the additional arrangements which are fitted on to the under-

Fig 4

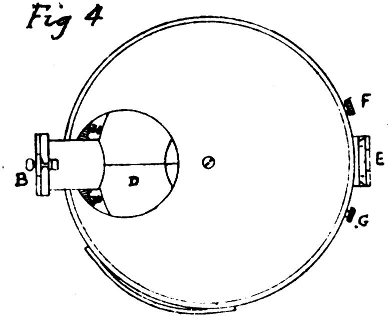


Fig 5

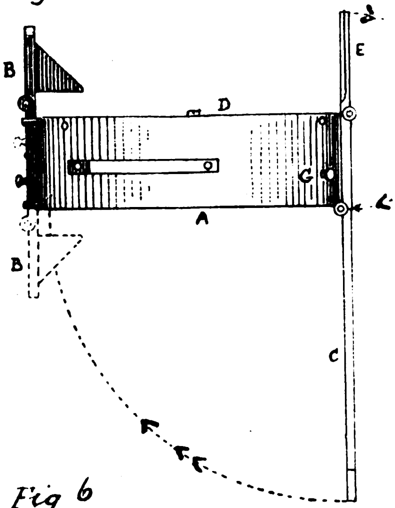
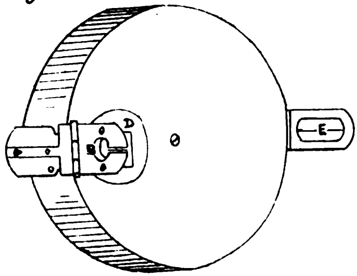


Fig 6



side of the prismatic compass for this purpose, so that when the prismatic compass shown in fig. 3 (page 26) is turned over, its side elevation will be as indicated in fig. 5. The sight-vane C being turned down upon the box in the direction indicated by the arrow upon the dotted line in fig. 5, the compass card is thrown off its bearing. A short sight-vane marked E, equal in height to the depth of the box, is raised at right angles as shown. When not in use as a clinometer the sight-vane E folds back outside the box, and when thus folded back upon the edge of the box, it clamps the clinometer card D in the same way as the folding down of the sight-vane C clamps the compass card A. The same prism, marked B, is available for reading both the compass card and the clinometer card, the prism being made to turn upon a pivot, half-way round in one direction, and is provided with a stop in the other direction to enable the surveyor to place it at right angles to the box in the positions shown by full and dotted lines in figure 5. When taking vertical angles the instrument is held between the thumb and the first and third fingers in the position shown in fig. 6, the second finger being placed

TABLE B

IST^{T} = 100	
	THICKN^{S}
	1·7
	3·5
	5·2
	7·0
	8·7
	10·5
	12·2
	14·0
	15·7
	17·5
	19·3
	21·0
	22·8
	24·6
	26·3
	28·1
	29·9
	31·7
	33·5
	35·3
	44·3
	53·6
	63·1
	72·8
	82·8
	93·3
	104·1
	115·5
	127·4
	140·0
	153·5
	167·8
	183·3

TABLE C

DEC^{S}	ONE IN
1	57·29
2	28·64
3	19·08
4	14·30
5	11·43
6	9·51
7	8·14
8	7·11
9	6·31
10	5·67
12	4·70
14	4·01
16	3·49
18	3·08
20	2·75
22	2·47
24	2·25
26	2·05
28	1·88
30	1·73
32	1·60
34	1·48
36	1·38
38	1·28
45	1·00

NOTE

SCALES OF INCHES DIVIDED IN EIGHTHS AND TENTHS, ARE ALSO MARKED UPON THE EDGES OF THE CLINOMETER RULE.

HE DEPARTURE FROM THE HORIZONTAL, EQUAL TO
OUNT OF RISE OR FALL PER 100 OF RUN HORIZONTAL
TAIN ANGLES UP TO 85°, WHEN THE INSTRUMENT
VERTICALLY AS IN THE FIGURE.

HE TRANSVERSE THICKNESS OF AN OBJECT, MEASURED
ICULAR TO THE LINE JOINING THE EYE WITH THE
OF THE OBJECT, WHEN THE NEAREST DISTANCE OF
ECT IS 100. — BY PLACING THE FACE OF THE INSTRUMENT
TAL, & THE FACE OF THE COMPASS PARALLEL TO IT, THE
BEARINGS AS WELL AS THE DISTANCE BETWEEN TWO
CAN BE OBTAINED.

CERTAIN ANGLES OF ELEVATION OR DEPRESSION, WHICH
TY OF VERTICAL MEASUREMENT PER AMOUNT OF
RIZONTAL.

Fig 4

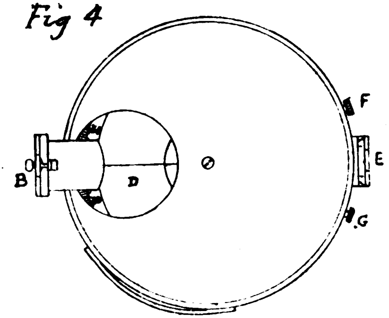


Fig 5

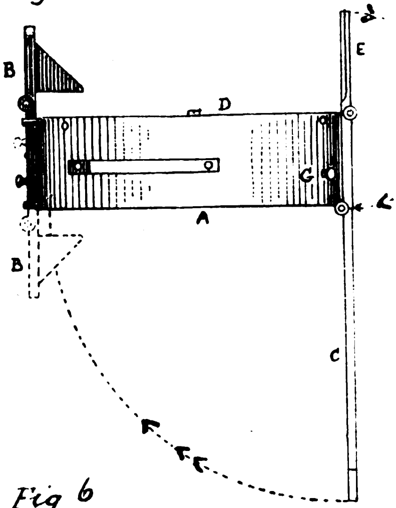
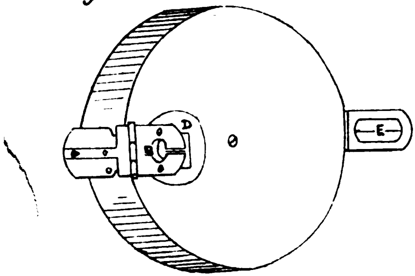


Fig 6



side of the prismatic compass for this purpose, so that when the prismatic compass shown in fig. 3 (page 26) is turned over, its side elevation will be as indicated in fig. 5. The sight-vane C being turned down upon the box in the direction indicated by the arrow upon the dotted line in fig. 5, the compass card is thrown off its bearing. A short sight-vane marked E, equal in height to the depth of the box, is raised at right angles as shown. When not in use as a clinometer the sight-vane E folds back outside the box, and when thus folded back upon the edge of the box, it clamps the clinometer card D in the same way as the folding down of the sight-vane C clamps the compass card A. The same prism, marked B, is available for reading both the compass card and the clinometer card, the prism being made to turn upon a pivot, half-way round in one direction, and is provided with a stop in the other direction to enable the surveyor to place it at right angles to the box in the positions shown by full and dotted lines in figure 5. When taking vertical angles the instrument is held between the thumb and the first and third fingers in the position shown in fig. 6, the second finger being placed

TABLE B

DIST = 100	
	THICKNS
	1·7
	3·5
	5·2
	7·0
	8·7
	10·5
	12·2
	14·0
	15·7
	17·5
	19·3
	21·0
	22·8
	24·6
	26·3
	28·1
	29·9
	31·7
	33·5
	35·3
	44·3
	53·6
	63·1
	72·8
	82·8
	93·3
	104·1
	115·5
	127·4
	140·0
	153·5
	167·8
	183·3

TABLE C

DECS	ONE IN
1	57·29
2	28·64
3	19·08
4	14·30
5	11·43
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8	7·11
9	6·31
10	5·67
12	4·70
14	4·01
16	3·49
18	3·08
20	2·75
22	2·47
24	2·25
26	2·05
28	1·88
30	1·73
32	1·60
34	1·48
36	1·38
38	1·28
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IZONTAL.

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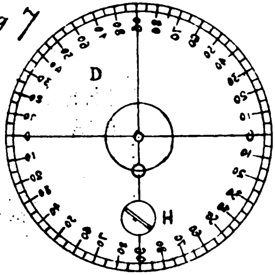
TILDEN FOUNDATIONS.

upon a button marked F, which presses a spring, by which the swing of the clinometer card is regulated. This card, D, is provided with an attached lead weight marked H in fig. 7, and is graduated as shown from zero upon a horizontal line to 90° at the top and bottom of the card. The figures upon the card are reversed so as to be read by the prism in the same manner as the figures upon the compass card. Either hand is selected according to the light. In fig. 6 the face of the clinometer is to the right. It is recommended that in taking vertical angles the line of sight should be directed at first upon some object in the same vertical plane, either above or below that which it is desired to observe, and the card brought to rest by the employment of the regulating button, F. When perfectly steady, gently raise or lower the sight-vane E, until the central hair or wire cuts the line of sight ranging between the eye and the point observed. In order to change the instrument into a prismatic compass, it is only necessary to fold down the sight-vane E, to turn the prism B to the reverse side of the box, and to raise the sight-vane C. This combination of compass clinometer has been patented by Lieut.-Colonel O'Grady Haley.

Fig 7



The form of clinometer most generally used is that known as the clinometer rule, which consists of two flat arms hinged together at the centre in a manner about to be described, and fixed so as to open and fold like an ordinary foot-rule, the arms being made broad enough to contain certain tables, which are referred to in our diagram as tables A, B and C. One of these tables is placed upon the front face and the other two upon the back of the rule. They are intended for use in the application of the instrument to vertical and horizontal measurements. Upon the edges of the rule, inches are also marked, sub-divided into eighths and tenths.

When the instrument is open it is seen that the head of the rule consists of two metal sliding pieces jointed, so as to turn accurately on the centre D. Each of these sliding pieces has a scale engraved upon it, both scales being, as shown in our illustration (pages 31-33), on the same side of the rule, and placed so that when the instrument is closed, the arrow marked A upon the inner scale points to zero upon the outer scale, and the arrow marked B upon the outer scale points to zero upon the inner scale. One of these scales expresses the angular amount of opening between the arms in terms of the degrees of a quadrant, while the other scale registers the inclination as a rise or fall of a certain number of inches per yard run of horizontal distance. Spirit levels are also fixed in the edges of each arm, enabling the observer to place either arm of the instrument horizontal when using it in a vertical direction. To the inner side of one arm upon the same edge as one of the spirit levels is attached an ordinary magnetic compass, contained in a box, which is constructed to turn to a horizontal plane when observations are being made vertically, and to fold back into recesses marked E and F when the instrument is closed. The needle is set free to revolve by a small stop-lever fitted into the side of the compass-box, and should always be lifted off its centre when not in use. To each end of the other arm of the rule are attached sight-vanes, consisting of metal plate, hinged so as to fold down flush upon its edge when they are not in use, as indicated by the curved dotted lines in the diagram. Each sight-vane has a small circular hole drilled at G, and a larger circular opening at H. The openings at H each contain a glass disc, upon which lines crossed at right angles accurately mark the centre, and guide the eye both vertically and in a direction parallel to the edge of the rule. When raised they serve as sights to view objects situated either above or below the level of the eye, in the manner explained by the direction of the arrows upon the diagram, marked as lines of sight when looking up or looking down. These lines of sight are parallel to one another and to the face of the rule, but are not coincident, as it will be observed upon reference to the end view marked K that the hole at G is not in the centre of the plate. This is because the two sight-vanes are not of the same width;

that at the end of the rule being as wide as the edge of the rule, while that at the head of the rule is reduced by the thickness of the outside sliding plate. In each sight-vane the small hole G serves as an eye-piece, and the diaphragm H gives the direction of sight when viewed from the opposite sight-vane: hence the positions of G and H are alternate, G being above H in the one, and below H in the other vane. With the use of the instrument vertically we are enabled approximately to measure heights by the application of Table A, while horizontal distances for certain angles of elevation or depression up to 45° can be calculated by the application of Table C. With the use of the instrument horizontally, lateral distances can be approximately ascertained by the application of Table B, and with the aid of the compass set parallel to the face of the rule the relative bearing of two defined distant points may be taken. The tables marked A, B and C depend upon the fact that when either the base or perpendicular of any right-angled triangle is known, and one of the remaining angles of that triangle can be measured, then the unknown length of either the perpendicular or base can be mathematically obtained. When using the instrument vertically as a batter level, the spirit bubble upon the inner edge of the lower arm is first set by the hand, and then maintained in as level a position as possible. The sight-vanes are raised and the upper arm lifted, until the cross line at H, when viewed at G in the opposite sight-vane, is either at the top of the object to be observed, or until it bisects any point upon that object which can be sufficiently localised to make a calculation reliable. Then the arrow-head upon each one of the metal sliding-pieces marked A and B respectively will point to the angle and inclination, to be read off the other sliding piece. As an example, suppose from a tower 120 ft. high that you can see an object through the sights when one scale reads 26°, and the other scale 18 in. per yard, with the instrument set as shown in the diagram; the upper arm then bears an inclination to the lower arm of the rule equal to a rise of 1 in 2, so that in this case the base would be about double the perpendicular height, and the object is found to be approximately 240 ft. distant. An inclination of 1 in 2 is more accurately expressed by an angle of 26° 34′, but the instrument only registers degrees. Referring to Table C, an amount of 2·05 is given as the amount of run horizontal per unit of vertical measurement for an angle of elevation or depression equal to 26°. Applying this ratio to the case under consideration, we find 2·05 × 120 = 246 ft. to be the distance of the tower from the object observed. Next, so as to compare the use of Table A with Table C, let us suppose the angle observed to be 30° and the tower to be at a horizontal distance of 100 units of length from the given object, we find upon applying the figures given in Table A, that the height of the tower would be 57·7 units of length; then if the height of the tower be known to be 57·7 units of length, and the distance of the tower from the object viewed be required, we find upon applying the figures given in Table C opposite 30° that the horizontal distance would equal 57·7 × 1·73 = 99·821, or practically 100 units of length, as was assumed when applying Table A. If the angle observed be 45°, then the height of the tower and the distance of the object from the tower are seen, upon reference to Tables A and C, to be equal to one another. By the use of Table B lateral or transverse distances can be arrived at, when the instrument is held with its face horizontal. When so placed the sights are arranged to be in a line with one extreme, say the left hand of the object, and the arm containing the sights is kept turned towards this point, while the other arm is moved out horizontally under its edge in a line with the right hand of the object, the head of the rule being placed as near as possible by the eye opposite the centre of the distance to be calculated, after the shortest or perpendicular distance between this point and the surveyor has been measured. The result gives the transverse thickness of an object parallel to the line LN and perpendicular to the direction of DM produced. If the angle LDN be 45° and the arms DL and DN measure each 6 inches, DM will, upon plotting these lengths and directions to a large scale, be found to measure 5·54 inches and LM 2·29 inches. If DM be produced so as to measure 100 units of length, then a line parallel to LN, subtending an angle of 45° at the head of the rule, gives 100 multiplied by 2·29, multiplied by 2 (because LN = 2LM), and, divided by 5·54, as the number of units of length required, *i.e.*, $100 \times \frac{2{\cdot}29 \times 2}{5{\cdot}54} = \frac{45800}{554} = 82{\cdot}8$, as stated in Table B. From this we can determine the transverse or lateral dimension at any greater horizontal distance. An object 400 ft. from an observer, subtending an angle of 45°, would be 4 × 82·8 = 331·2 ft. in width.

Independent of the tables, the rough inclination of mountain slopes and the dip of strata in a shaft may be determined by the clinometer. The instrument can also be used for setting out the pitch of roofs or to check their inclination according to the table given in the left hand at the top of our diagram (pages 31-33). Having laid the under edge of the lower arm upon the slope to be measured, the upper arm is raised vertically until the bubble of the spirit level upon its top edge appears in the centre of its run. The angle or the inclination of the given slope is then found to be registered upon the scales at the head of the instrument, and the amount is read off and booked. All engineers and surveyors are, however, agreed that the method of determining relative heights by means of vertical angles does not give the same degree of accuracy as can be obtained by a careful system of levelling. (See pages 179-185.)

Dr. Bates' Improved Drain Clinometer is a thoroughly well-made and reliable instrument, 12½ inches long, for the use of Builders, Medical Officers of Health, Sanitary Inspectors and others, for testing the slope of drain pipes. The arc is fixed at the extreme end of the Clinometer, so as to allow of a close reading and distinct graduation, and is divided on one edge to degrees and quarter degrees, and on the other edge to gradients of 1 in 20, 1 in 30, 1 in 40, 1 in 50, 1 in 60, 1 in 70, and 1 in 80, 1258, with electrum fittings; 1259, with brass fittings; 1260, with magnetic compass.

CHAPTER VI.

THE VERNIER.

BEFORE proceeding to describe instruments which measure fractional proportions of given lengths, it is necessary clearly to understand the principle of a vernier scale, which is a contrivance for measuring off portions of a sub-division upon the edge of a scale, the result being obtained by recording the differences between the divisions of two approximating scales, one sliding over the other.

The general principle may be thus illustrated. If the line AB (fig. 1, page 40) represents the length of two primary divisions upon a continuous circle, or upon a straight line of any required length, and if, for example, each of these main divisions be subdivided into two equal portions, as shown upon the lower portion of the line AB, then a sliding scale of the length of these two subdivisions containing equal divisions amounting to one more in number than the number of subdivisions upon the primary scale, will enable us to read to amounts equal to one-sixth of a main division upon the primary scale. To render the application of this clear, each main division upon the line AB is shown subdivided into six equal parts, and the sliding scale is represented in seven different positions along the line AB. In reality the subdivisions into one-sixth parts upon the line AB would not exist. The line AB would simply represent the edge between the vernier and the primary scale. The vernier or sliding scale is read in each case at the *coincidence* of one of its subdivisions, with a division upon the primary scale, and the number of the sixths to be taken, is furnished by the number of the subdivisions which appears to coincide with a division upon the primary scale. Thus, when the zero point indicated by the arrow upon the vernier has travelled towards B, a distance

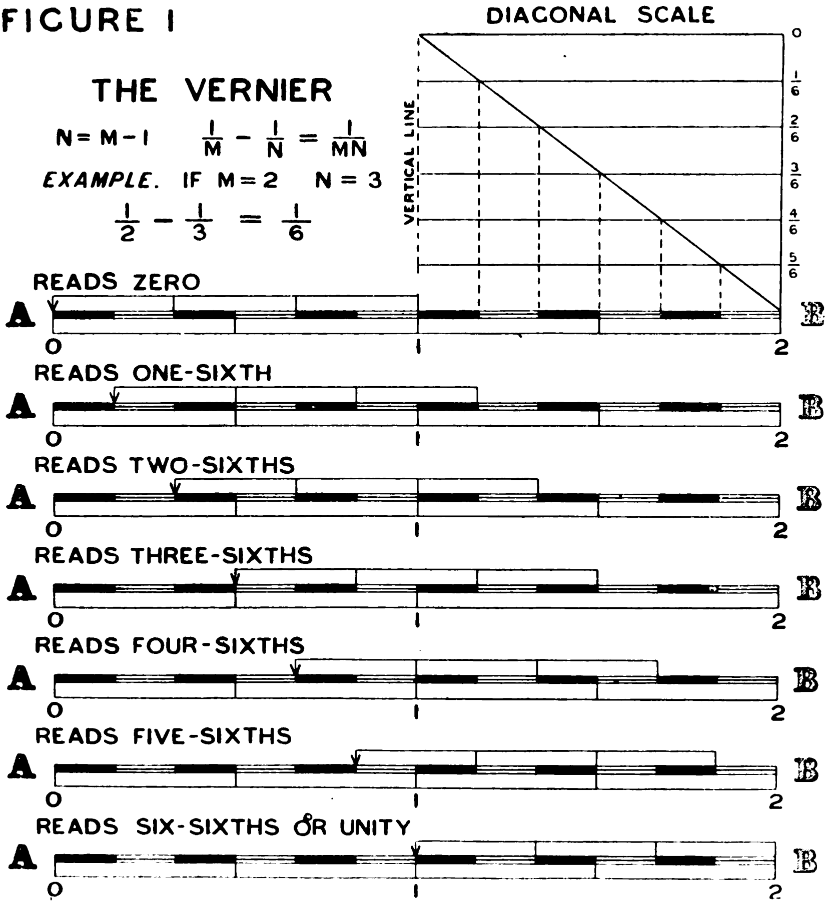
FIGURE I

THE VERNIER

$N = M - 1 \qquad \frac{1}{M} - \frac{1}{N} = \frac{1}{MN}$

EXAMPLE. IF $M = 2 \qquad N = 3$

$$\frac{1}{2} - \frac{1}{3} = \frac{1}{6}$$



of one-sixth of a main division from A, the coincidence appears at the first division from the arrow. For a reading of two-sixths, the coincidence appears at the second division from the arrow; and for three-sixths or one-half of a main division the arrow itself coincides with the subdivision upon the primary scale. For a reading of four-sixths the coincidence is similar to one-sixth, but as the arrow in travelling from A towards B has passed the first half subdivision from zero, the one-sixth must be added to the one-half, which gives four-sixths; and, in the same way, two-sixths added to one-half gives a total of five-sixths. The minor divisions in the length of AB are added solely to prove the above statement to be correct, as the arrow upon the vernier scale will be seen to point in each case to the number of sixth parts read at the coincidence of one of the subdivisions upon the vernier scale with a subdivision upon the primary scale.

It will be thus seen that the same result is obtained by means of the vernier scale as would be furnished by the plotting of a diagonal scale upon paper, as shown in the diagram (page 40).

The principle of the vernier was first enunciated in 1542 by Peter Nonius, and its application subsequently demonstrated by Pierre Vernier in 1631. Hence its name, and its construction, as follows:—

If $x =$ the length of a division upon the fixed scale, commonly called the primary scale,

and $y =$ the length of a division upon the movable scale, commonly called the vernier scale,

then $(n - 1)\, x = ny \therefore y = x - \frac{x}{n}$

so that y, a division upon the vernier scale, is smaller than x, a division upon the primary scale, by the n^{th} part of x.

The application of the principle of such fractional scales to angular instruments may be easily understood.

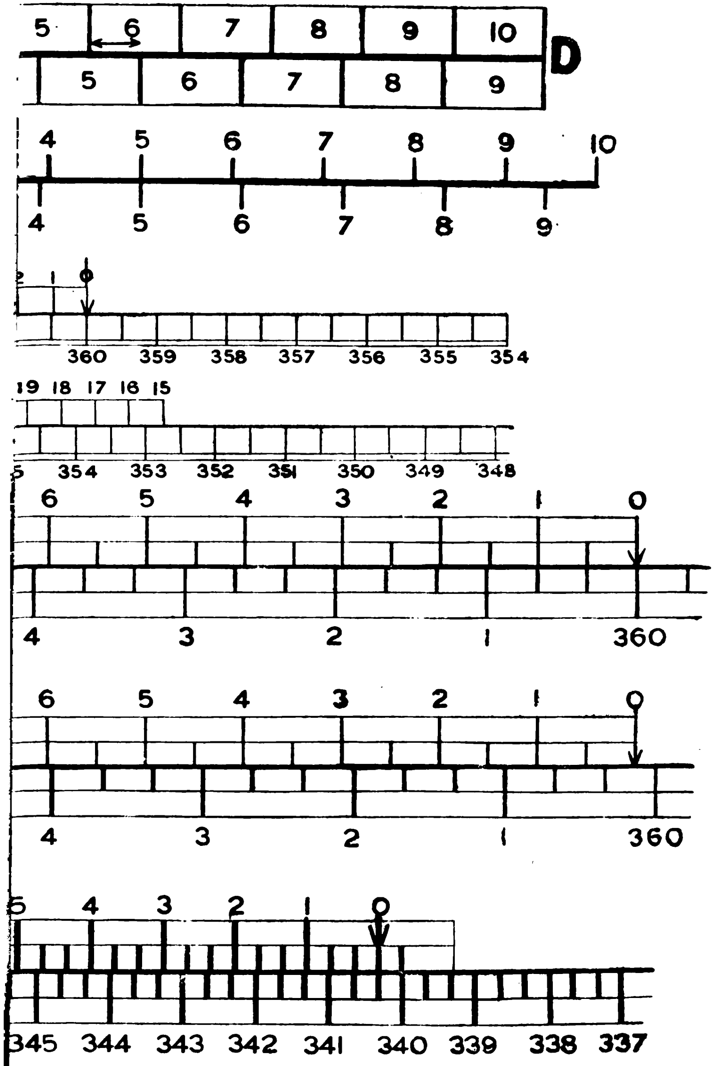
The vernier scale is made to slide evenly along the graduated limb of an instrument, and is constructed in compliance with the above conditions to consist of a total length of a number of divisions of the primary scale, less by one than the number of smaller divisions into which those primary divisions are to be sub-divided. By its use, distances or amounts of deviation can be minutely measured with a degree of accuracy unattainable with the application of a single scale closely sub-divided, as in the latter case, the strokes indicating the divisions would come so near together, that it would be difficult to distinguish one from the other, even when read through a powerful lens.

The principle may be thus recited: If a line be divided into m number of equal parts on one side, and into $(m+1)$ number of equal parts on the other side, the length occupied by the difference between each of these divisions will be equal to the length of the line divided by the product of the number of parts taken on each side, or mathematically expressed by the fraction $\frac{1}{m\,(m\,+\,1)}$; thus, in fig. 1 (pages 44-46), the line AB being divided into three and four equal parts, the difference between these parts equals $\frac{1}{3 \times 4}$ or one-twelfth ($m = 3$, $m + 1 = 4$ and $\frac{1}{m\,(m+1)} = \frac{1}{12}$). This will be evident upon reference to the foot-scale shown under the line AB. If the line AB be supposed to be 12 in. long, the difference between one-third and one-fourth is one-twelfth, or 1 in., the difference between two-thirds and two-fourths is two-twelfths, or 2 in.; and the difference between three-thirds and three-fourths is one-fourth, or 3 in. Applying this principle to fig. 2, we obtain by dividing the line CD into nine and ten equal parts respectively, a length between these divisions equal to $\frac{1}{90}$ of the whole line. Now if the upper line of divisions be supposed to represent the vernier, and if the zero point indicated by the arrow in fig. 3 has been moved forward so that the line at 5 upon the upper scale coincides with a line or stroke upon the lower scale, then the arrow will have travelled $\frac{5}{90}$ of the whole length of CD along its edge from the zero upon the lower scale of divisions, or half way from the zero towards the next division upon the primary scale.

The limbs so graduated may be either straight or circular. In circular instruments which record angles, the primary scale is graduated into degrees, each degree of the circle being sub-divided into two or three equal parts, denoting 30 or 20 minutes respectively, while the introduction of a vernier will enable this scale or division to be read to minutes or such parts of minutes as may be required. For instance, let us suppose, as shown in fig. 4, that we have to deal with an instrument in which the primary scale is divided into degrees and half-degrees, and that we desire to construct a vernier which shall enable us to read to minutes. One minute being a thirtieth part of each sub-division of the primary scale, we must take 29 divisions on this scale, and divide it into 30 equal parts upon the vernier. Thus, if $m + 1 = 30$, $m = 29$, and the product $\frac{1}{m\,(m+1)} = \frac{1}{29 \times 30} = \frac{1}{870}$ of the whole length of 29 divisions so taken; but as each of these divisions is equal to half a degree, we have $\frac{1}{870} \times \frac{29}{2} = \frac{1}{60}$ of a degree as the result of the division obtained by the vernier: hence the vernier will read to minutes. It will be observed, in figs. 4 to 8, that the numbering upon both the primary and the vernier scales reads from right to left. This is because the two scales in circular instruments are placed upon a circle situated at or near the outer edge, and the instrument is worked round with the sun from the centre of that circle. Circular protractors and theodolites are thus constructed, but in the box sextant the numbering reads from left to right, when viewed as held in the hand for work.

Fig. 5 shows the same vernier as fig. 4, but with the zero point in the centre. This arrangement is adopted by some makers in the manufacture of their circular protractors, which we shall hereafter describe. The divisions are the same as in fig. 4, but the right-hand half of the vernier, numbered 15 to 0, is placed upon the left-hand side of the

[*Field Work and Instruments, pp.* 44, 45, 46.



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half numbered 30 to 15. To understand this better, we may compare it to a foot rule or split-divided scale, in which the inches are marked to read first, 6 to 12, and then 1 to 6, instead of 1 to 12 continuously. In fig. 6 the primary scale consists of degrees and thirds of a degree, and a vernier is constructed reading to 30 seconds: thus a length of 39 divisions on the primary scale is divided into 40 equal parts upon the vernier, 30 seconds being one-fortieth part of a sub-division on the primary scale, each of which sub-divisions equals 20 minutes. Here $m+1=40$, $m=39$, and $\frac{1}{m(m+1)}=\frac{1}{39\times 40}=\frac{1}{1560}$ of the whole length of 39 divisions, equal to 13 degrees, or 780 minutes, hence $\left(\frac{1}{39}-\frac{1}{40}\right)=\frac{1}{1560}\times\frac{13\times 60}{1}=\frac{1}{2}$ minute. In order to read the minutes correctly upon the vernier, every alternate division only is numbered, the intermediate divisions, which are made shorter for sake of clearness, indicating half-minutes. In our diagram the curved graduated limbs are shown developed into horizontal or straight members, and in practice the strokes indicating the divisions are carefully cut and numbered upon the circular plates at the works by a machine, so fixed as to reduce them from a large pattern, upon which the figures and lines have been accurately set out.

Fig. 7 indicates the same primary scale of divisions and the same vernier as in fig. 6; but in fig. 7 the arrow at the zero point has travelled forward a certain proportion of the full sub-division of one-third of a degree on the primary scale. Now, the vernier enables us to see that this amount equals 8 minutes, according to the principle illustrated in fig. 3. In reading off the graduated limb of the instrument, we must first look to the arrow at zero on the vernier, and having read the number on the primary graduated scale of divisions next this arrow, which appears upon the zero side of the primary scale, the eye is passed along the vernier scale until some one of its lines coinciding with any line upon the primary scale is found, and having determined with the aid of a magnifying eye-piece the number of the divisions so indicated by the stroke which most nearly coincides with a division on the primary continuous circle, this number is added to the reading already determined on the primary scale. We are not concerned as to what division upon the graduated limb is so cut, our object being only to arrive at the fractional proportion of the division upon the graduated limb at which the arrow on the vernier stands, this fractional amount being indicated by the number on the vernier which coincides with a stroke on the primary scale. When a coincidence is observed, as in fig. 6, simultaneously at the zero and the last stroke on the vernier, it indicates zero to be added, and the division on the graduated limb which coincides with the arrow marked at zero upon the vernier indicates exactly the amount. Fig. 8 illustrates a vernier reading to 20 seconds, 59 divisions on the primary scale are divided into 60 divisions upon the vernier, and the result gives $\left(\frac{1}{59} - \frac{1}{60}\right) = \frac{1}{3540}$ of a length of $19\frac{2}{3}$ degrees, or $\frac{1}{3540} \times \frac{59}{3} = \frac{1}{60}$ of each sub-division or 20 seconds. Hence upon the vernier scale, for sake of clearness in reading, every third stroke only is marked. Other verniers can be similarly constructed, but figs. 4 to 8 illustrate those most generally adopted. The student is recommended to draw out vernier scales to a large size, and practise reading the result of sliding them along the edge of a primary scale, drawn to suit definite units.

CHAPTER VII.

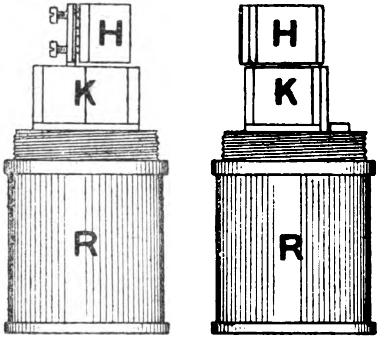
REFLECTING INSTRUMENTS.

When a ray of light is reflected at a plane surface, the reflection takes place in a plane perpendicular to the reflecting surface, the incident and reflected rays making equal angles with this surface.

The Line Ranger.—This instrument, the use of which is explained in our illustration (page 50), enables the surveyor to find an intermediate station upon a given base line, and is useful where great accuracy in the determination of any required point in a line is essential.

Holding the instrument vertically in his hand or upon the top of a rod which can be subsequently located upon the base line, the surveyor walks transversely to the line AB towards C until the coincidence of the poles at A and B in the prisms of glass at C situated intermediately upon the line is clearly observed.

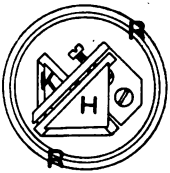
The Optical Square.—This instrument is used for setting out perpendicular lines and long offsets. It commends itself on account of its portability, being about the size of a large watch, and forms a circular box consisting of an outer tube attached to one side, and an inner tube attached to the other side, the one cylinder sliding laterally within the other, and maintained in position by a small fixed screw connexion, which will be seen in the outer rim or circular side of the instrument. The inner circular portion can thus be twisted round by the hand to allow of three apertures through both tubes at the side, one open for nearly the whole depth of the side, one open for about half the depth of the side, and a small circular hole to serve as an eye-piece. When not in use, the inner tube can be twisted round to close the apertures, and thus prevent dust working its way to the inside. (See page 52.)



LINE RANGER—LARGE SIZE

BOX CLOSED

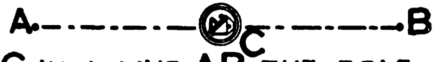
SMALL SIZE INSTRUMENT



PLAN

NOTE

THIS INSTRUMENT IS USED AS A LINE RANGER FOR DETERMINING THE POSITION OF ANY INTERMEDIATE POINT



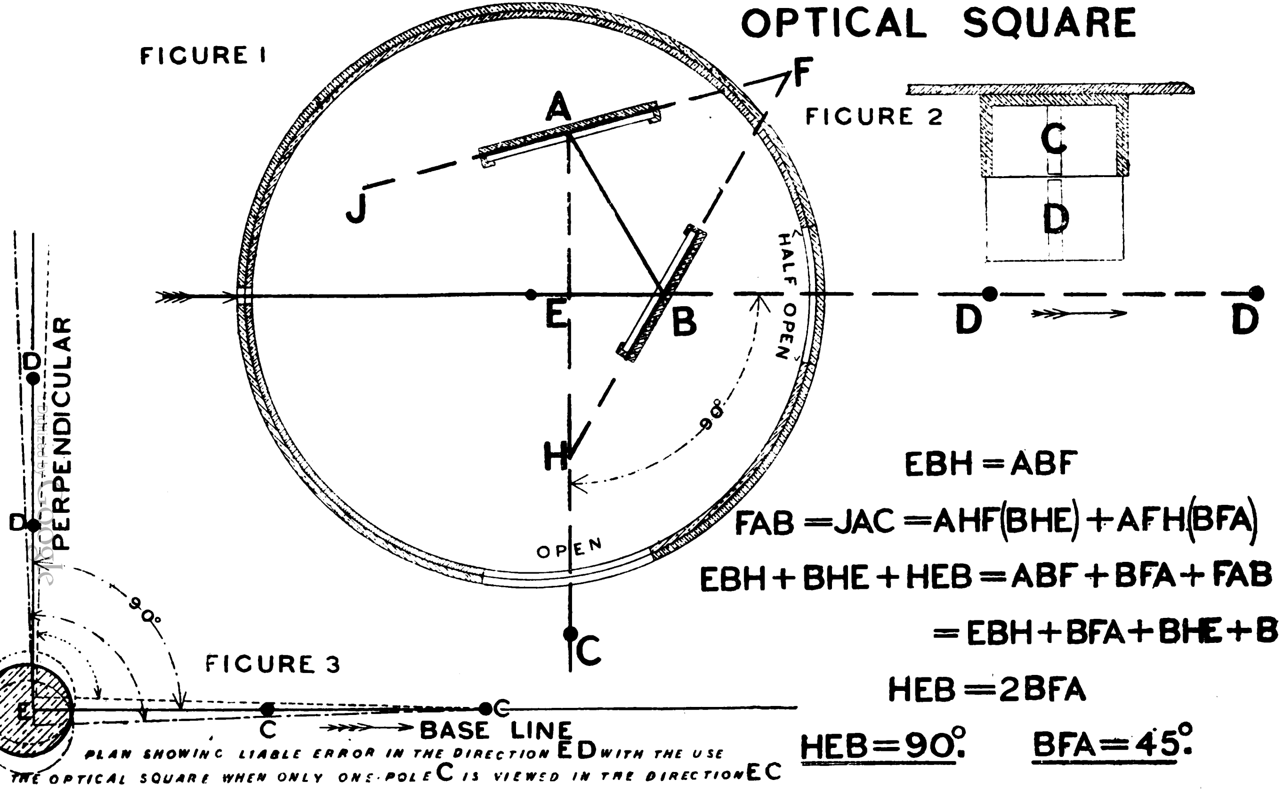
C IN A LINE AB THE POLE ON THE LEFT HAND BEING REFLECTED IN THE LOWER PRISM & THE POLE ON THE RIGHT HAND REFLECTED OVER IT IN THE UPPER PRISM.——

Fig. 1 (page 52) illustrates an enlarged section with the top-plate of the inner tube removed, so as to show the two glasses marked A and B which are permanently fixed by the makers, in vertical planes intersecting one another at an angle of 45°. The glass marked A is formed entirely of silvered glass, while the glass marked B is silvered for only half its depth, as indicated in fig. 2, which shows the attachment to the upper plate in the diagram (page 52), to which plate they are fastened by sunk rivets. In using the instrument, the surveyor holds it horizontally in one hand; placing his eye opposite the glass B, at the arrow in fig. 1, and looking towards D, he observes the object or pole D, through the plain or unsilvered portion of the glass B, while a pole at C (if the angle CED forms a right angle), will be reflected from the looking-glass at A, and seen in the silvered portion of the glass at B, one pole coming in line over the other, as indicated in fig. 2. The mathematical proof given in the diagram depends upon the angle of incidence JAE being equal to the angle of reflection BAF so far as the glass A is concerned, and the angle of incidence ABF being equal to the angle of reflection EBH so far as the glass B is concerned. The exterior angle of the triangle AHF is equal to its two interior and opposite angles, and these angles can be named for purposes of further application as the angles BHE and BFA, as shown in brackets on line 2. Then the three angles of the triangle EBH being equal to the three angles of the triangle ABF, and one of the angles in the triangle ABF being proved equal to the sum of the two angles BHE and BFA, we obtain, by substituting these values, an equation in which the angles EBH and BHE appear common to both sides: hence the remaining angles are equal, and the angle HEB formed by the intersection of the lines ED and EC at the point over which the instrument is held, is seen to be double the angle BFA formed at the intersection of the planes contained by the mirrors.

Every ray of light which falls upon the first mirror A is thence reflected to the second mirror B at the same angle. It matters not where the mirrors are fixed within the box so long as the angle JFB is correct, and that they are in a suitable field of view. A side set screw enables the mirror A to be adjusted, by slackening and finally tightening up as required, so as to be vertically parallel to the other glass when the instrument is held horizontally.

Fig. 3 shows a precaution to be observed when great accuracy is required by viewing two poles instead of one in the required direction. It is evident that if the dotted lines be continued for any length, the direction of the required perpendicular would deviate considerably from that indicated by the full line, while the position of the surveyor at E might depart but very slightly from the direction of the given line EC. With the use of a second pole in the line EC this error of deviation would be at once detected, and by setting two poles with the instrument in the line ED,

OPTICAL SQUARE



PLAN SHOWING LIABLE ERROR IN THE DIRECTION ED WITH THE USE THE OPTICAL SQUARE WHEN ONLY ONE POLE C IS VIEWED IN THE DIRECTION EC

$$EBH = ABF$$

$$FAB = JAC = AHF(BHE) + AFH(BFA)$$

$$EBH + BHE + HEB = ABF + BFA + FAB$$

$$= EBH + BFA + BHE + BF$$

$$HEB = 2BFA$$

$$\underline{HEB = 90°.} \qquad \underline{BFA = 45°.}$$

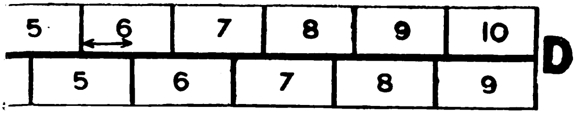
the direction could be more accurately continued than when only one pole is employed. Fig. 1 may be taken to illustrate the use of the instrument for setting out a perpendicular to the right-hand side of the surveyor, in which case the optical square is held in the left hand, and the surveyor directs his assistant with his right hand. Fig. 3 illustrates setting out a perpendicular to the left hand of a given line, in which case the instrument is simply turned over, held in the surveyor's right hand, his assistant being directed by his left hand. Thus the open portion of the side, which allows the pole to be reflected in the mirror at A, is left unimpeded by the surveyor's hand holding the instrument. In each case the assistant has to keep his pole upright, and to follow the direction of the surveyor as to moving the pole to be set out, either right or left, until one pole is reflected over the other in the glass B. When this coincidence takes place, the pole is fixed in the ground, and the right angle is said to be set out. (See also figures 5 and 6, page 64.) Should the lateral object be a fixture, such as the corner of a building, and the position of a perpendicular line therefrom to the base line be required, the surveyor proceeds in the same way, but walks backwards and forwards upon the main line, until the reflected image of the side object apparently coincides in a vertical direction with the pole upon the base line at which the surveyor is looking.

If the optical square is out of adjustment, accurate work can only be obtained by a longer process than that illustrated in fig. 3 (page 52). We must then observe a distant point at the point E upon the base line near where the perpendicular is desired, and having thus fixed this point, observe the point D by walking from E towards D unless D appears in the instrument to coincide with C, then bisect the distance between the two positions at E, so obtained, and the position of a perpendicular is determined, and a parallel thereto would give a perpendicular at any fixed point desired between E and D. The adjustment of the fixed glasses can be best effected by the makers.

half way from the zero towards the next division upon the primary scale.

The limbs so graduated may be either straight or circular. In circular instruments which record angles, the primary scale is graduated into degrees, each degree of the circle being sub-divided into two or three equal parts, denoting 30 or 20 minutes respectively, while the introduction of a vernier will enable this scale or division to be read to minutes or such parts of minutes as may be required. For instance, let us suppose, as shown in fig. 4, that we have to deal with an instrument in which the primary scale is divided into degrees and half-degrees, and that we desire to construct a vernier which shall enable us to read to minutes. One minute being a thirtieth part of each subdivision of the primary scale, we must take 29 divisions on this scale, and divide it into 30 equal parts upon the vernier. Thus, if $m + 1 = 30$, $m = 29$, and the product $\frac{1}{m\,(m+1)} = \frac{1}{29 \times 30} = \frac{1}{870}$ of the whole length of 29 divisions so taken; but as each of these divisions is equal to half a degree, we have $\frac{1}{870} \times \frac{29}{2} = \frac{1}{60}$ of a degree as the result of the division obtained by the vernier: hence the vernier will read to minutes. It will be observed, in figs. 4 to 8, that the numbering upon both the primary and the vernier scales reads from right to left. This is because the two scales in circular instruments are placed upon a circle situated at or near the outer edge, and the instrument is worked round with the sun from the centre of that circle. Circular protractors and theodolites are thus constructed, but in the box sextant the numbering reads from left to right, when viewed as held in the hand for work.

Fig. 5 shows the same vernier as fig. 4, but with the zero point in the centre. This arrangement is adopted by some makers in the manufacture of their circular protractors, which we shall hereafter describe. The divisions are the same as in fig. 4, but the right-hand half of the vernier, numbered 15 to 0, is placed upon the left-hand side of the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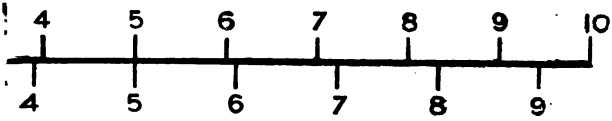
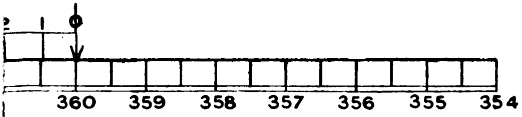
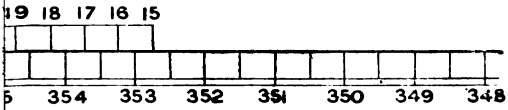
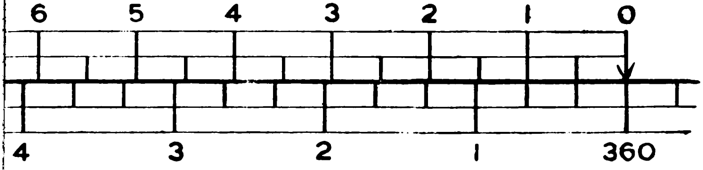
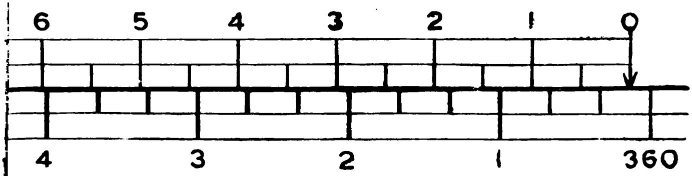
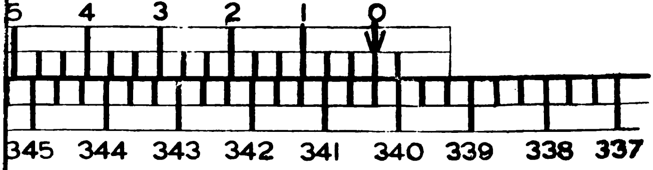












OPTICAL SQUARE

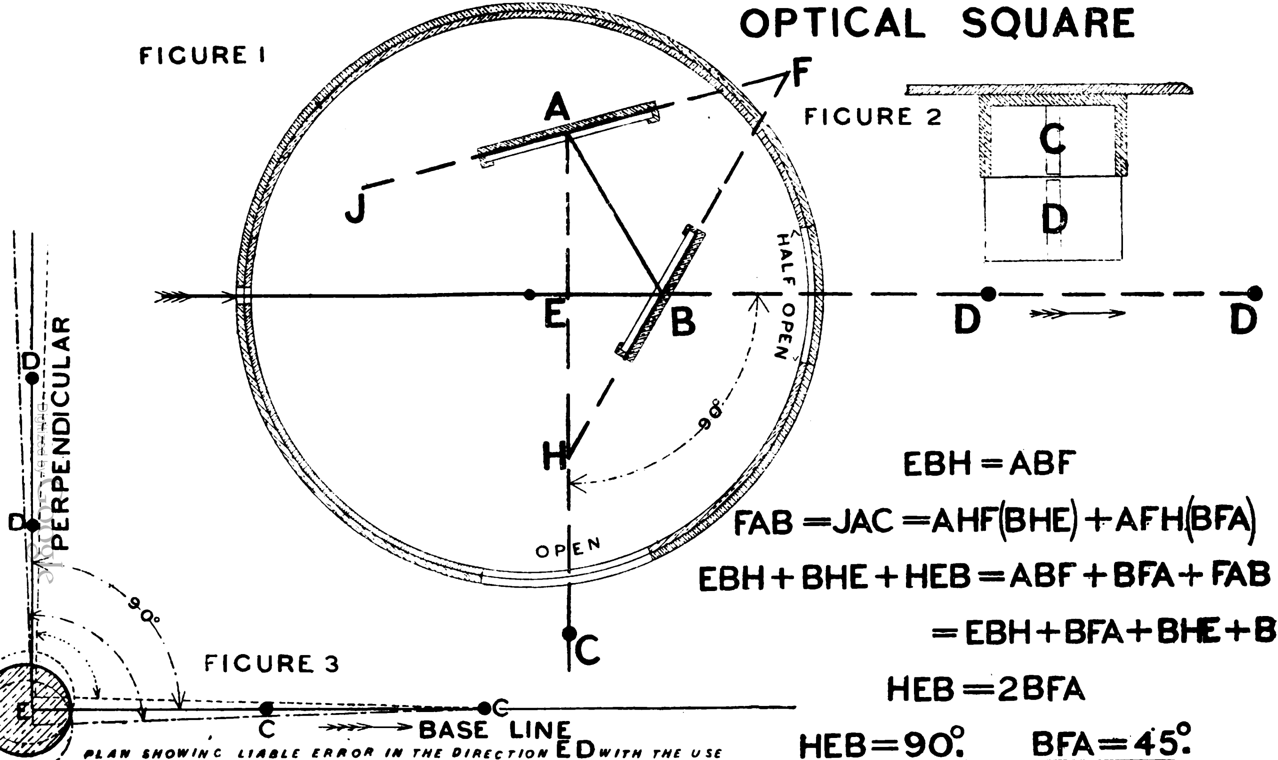


FIGURE 1

FIGURE 2

FIGURE 3

PLAN SHOWING LIABLE ERROR IN THE DIRECTION ED WITH THE USE THE OPTICAL SQUARE WHEN ONLY ONE POLE C IS VIEWED IN THE DIRECTION EC

$$EBH = ABF$$

$$FAB = JAC = AHF(BHE) + AFH(BFA)$$

$$EBH + BHE + HEB = ABF + BFA + FAB$$

$$= EBH + BFA + BHE + BF$$

$$HEB = 2BFA$$

$$\underline{HEB = 90^\circ.} \qquad \underline{BFA = 45^\circ.}$$

the direction could be more accurately continued than when only one pole is employed. Fig. 1 may be taken to illustrate the use of the instrument for setting out a perpendicular to the right-hand side of the surveyor, in which case the optical square is held in the left hand, and the surveyor directs his assistant with his right hand. Fig. 3 illustrates setting out a perpendicular to the left hand of a given line, in which case the instrument is simply turned over, held in the surveyor's right hand, his assistant being directed by his left hand. Thus the open portion of the side, which allows the pole to be reflected in the mirror at A, is left unimpeded by the surveyor's hand holding the instrument. In each case the assistant has to keep his pole upright, and to follow the direction of the surveyor as to moving the pole to be set out, either right or left, until one pole is reflected over the other in the glass B. When this coincidence takes place, the pole is fixed in the ground, and the right angle is said to be set out. (See also figures 5 and 6, page 64.) Should the lateral object be a fixture, such as the corner of a building, and the position of a perpendicular line therefrom to the base line be required, the surveyor proceeds in the same way, but walks backwards and forwards upon the main line, until the reflected image of the side object apparently coincides in a vertical direction with the pole upon the base line at which the surveyor is looking.

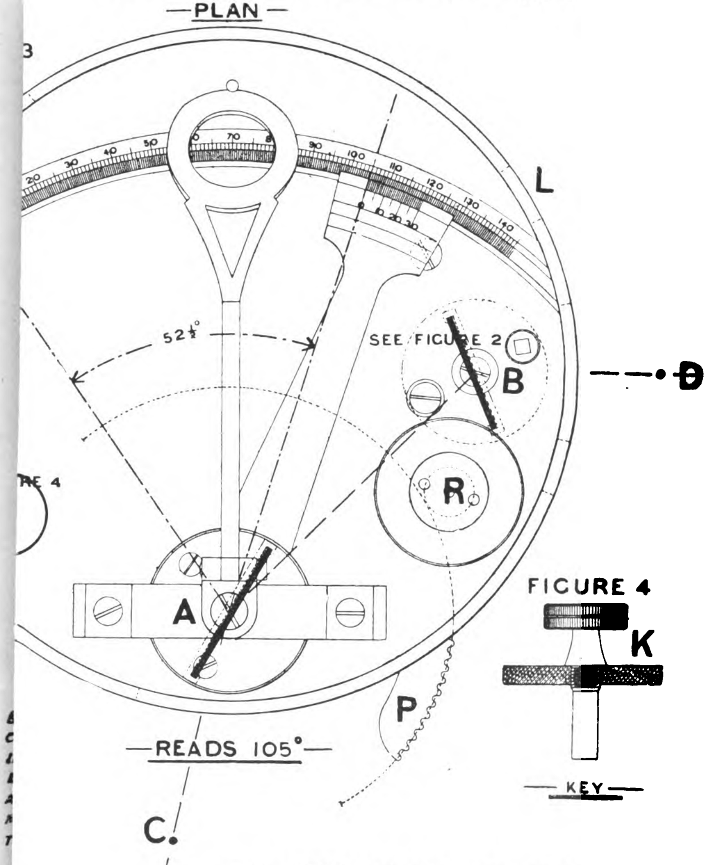
If the optical square is out of adjustment, accurate work can only be obtained by a longer process than that illustrated in fig. 3 (page 52). We must then observe a distant point at the point E upon the base line near where the perpendicular is desired, and having thus fixed this point, observe the point D by walking from E towards D unless D appears in the instrument to coincide with C, then bisect the distance between the two positions at E, so obtained, and the position of a perpendicular is determined, and a parallel thereto would give a perpendicular at any fixed point desired between E and D. The adjustment of the fixed glasses can be best effected by the makers.

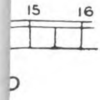
CHAPTER VIII.

THE BOX SEXTANT.

THE Box Sextant, as its name indicates, is an angular instrument enclosed in a box, which is unscrewed when required for use. It posesses the advantage of being portable and of requiring no other support than the hand. As a pocket instrument its accuracy of reading, in comparison with magnetic instruments, is greatly in its favour. The principle of this instrument resembles that of the optical square in depending primarily upon the following facts:—(1) When a ray of light is reflected at a plane surface the reflection takes place in a plane perpendicular to the reflecting surface, the incident and reflected rays making equal angles with this surface; (2) when a ray of light proceeds in a plane, at right angles to each of two plane mirrors, inclined at any angle to one another, and is successively reflected at the plane surfaces of the mirrors, the total deviation of the ray is double the angle of inclination between the mirrors. The angles so formed by the glass mirrors in the case of the optical square was seen to be fixed at 45°, giving a right angle between two directions; but in the case of the box sextant, one glass, namely, the one containing the complete mirror, is constructed to revolve upon a centre, and worked by means of a curved rack-and-pinion wheel, concealed within the box as shown in fig. 1. This glass is called the index glass, and is marked A in our illustration (pages 55-57). The glass marked B is called the horizon glass, and is fixed in a plane perpendicular to that of the instrument. For convenience of carrying the instrument it forms, when closed, a box of about 3 in. in diameter and 1½ in. deep. The top cover which protects the plate, shown in fig. 3 (pages 55-57), is reversible so as to be unscrewed and attached by an under screw beneath the box, thus forming a handle for holding

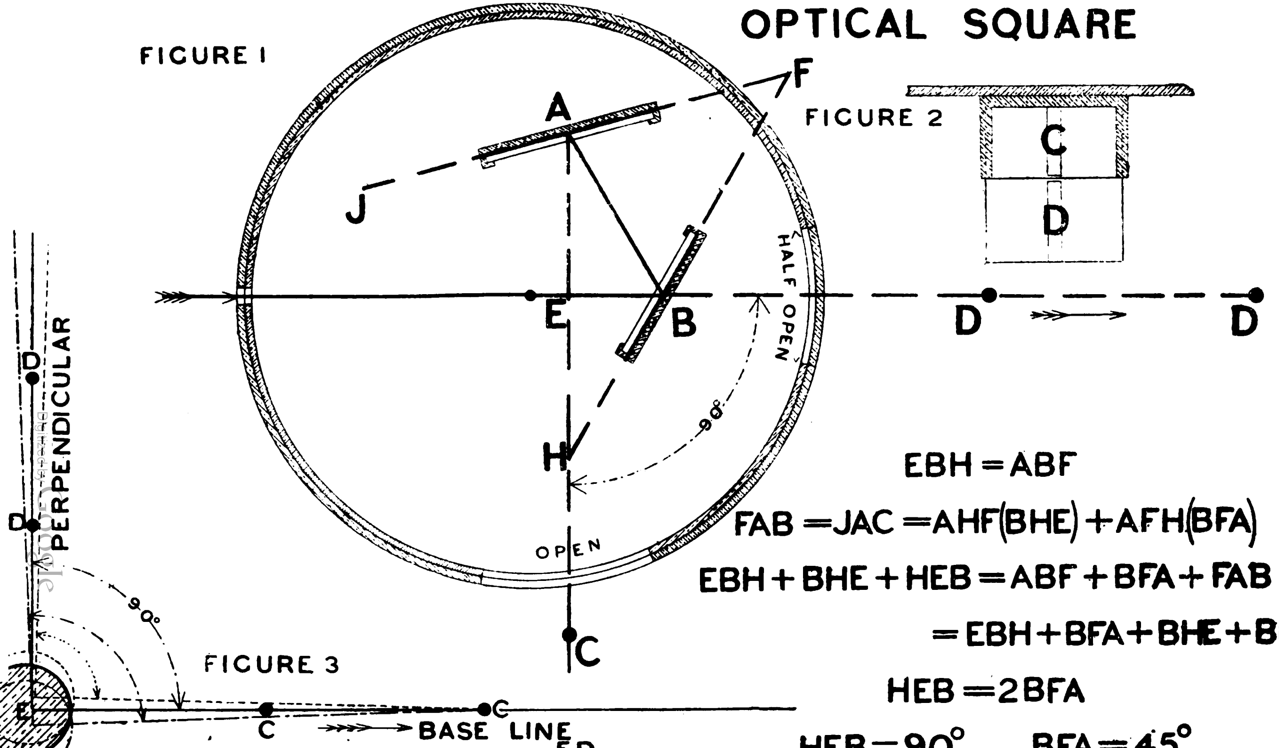
[*Field Work and Instruments*, *pp.* 55, 56, 57.





NOTE—CED EQUALS THE ANGLE REQUIRED TO BE TAKEN AT THE POINT E BETWEEN THE LINES CE AND ED.—SEE PRECAUTION ILLUSTRATED IN FIGURE 10.— AFB(JFH) EQUALS THE ANGLE FORMED BY THE PLANES OF THE MIRRORS.— WHEN THE INSTRUMENT IS SET TO ZERO, THIS ANGLE IS INFINITE.—SEE FIGURE 6.—

OPTICAL SQUARE



EBH = ABF

FAB = JAC = AHF(BHE) + AFH(BFA)

EBH + BHE + HEB = ABF + BFA + FAB

= EBH + BFA + BHE + BFA

HEB = 2BFA

HEB = 90°. BFA = 45°.

PLAN SHOWING LIABLE ERROR IN THE DIRECTION ED WITH THE USE THE OPTICAL SQUARE WHEN ONLY ONE POLE C IS VIEWED IN THE DIRECTION EC

the direction could be more accurately continued than when only one pole is employed. Fig. 1 may be taken to illustrate the use of the instrument for setting out a perpendicular to the right-hand side of the surveyor, in which case the optical square is held in the left hand, and the surveyor directs his assistant with his right hand. Fig. 3 illustrates setting out a perpendicular to the left hand of a given line, in which case the instrument is simply turned over, held in the surveyor's right hand, his assistant being directed by his left hand. Thus the open portion of the side, which allows the pole to be reflected in the mirror at A, is left unimpeded by the surveyor's hand holding the instrument. In each case the assistant has to keep his pole upright, and to follow the direction of the surveyor as to moving the pole to be set out, either right or left, until one pole is reflected over the other in the glass B. When this coincidence takes place, the pole is fixed in the ground, and the right angle is said to be set out. (See also figures 5 and 6, page 64.) Should the lateral object be a fixture, such as the corner of a building, and the position of a perpendicular line therefrom to the base line be required, the surveyor proceeds in the same way, but walks backwards and forwards upon the main line, until the reflected image of the side object apparently coincides in a vertical direction with the pole upon the base line at which the surveyor is looking.

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TILDEN FOUNDATIONS.

the instrument when in use (fig. 3, page 64). These screws for attaching the box or cover to the upper or lower side of the instrument run round the outside lower edge of the circumference of the instrument. The angles observed by a sextant being double the angles moved over by the index, the limb of the instrument is graduated, as shown in fig. 3 (pages 55-57), as though it were double the size, in order to record absolutely the angle observed. The angles are marked to read from zero to 140°; but it is to be noticed that after passing 120° the angles become less reliable. The divisions, zero to 140°, are usually marked upon a silvered plate, and have a vernier scale attached, which works upon the end of a bar, to which is fixed upon the inside, below the top plate, the movable index mirror. This mirror, with its attached vernier-bar, is revolved by means of the milled screw R, in fig. 3, which acts on the rack and pinion shown in fig. 1. The horizon-glass is half-silvered and half-unsilvered, and is attached to the top plate, as shown in fig. 2, connected in a manner capable of adjustment, and designed to secure the apparent coincidence in the direction of observation with a reflected image and an object viewed. Before screwing the cover to the underside of the instrument a small slide shutter must be opened in the lower plate to allow of two darkening glasses being lowered by means of two levers, which appear in the side of the instrument, generally just under the zero point of the graduated plate. These two coloured glasses, which are made to fold inside when the box is closed, are intended for astronomical purposes, and are to be used when observing the altitude of an object such as the sun, one or both of the darkening glasses being left in position according to the brilliancy of the object viewed. Thus they are of service at sea as shades when obtaining the altitude of the sun; that is to say, you look at the horizon through the plain portion of the glass B, and then bring the edge of the sun to the horizon with the little milled head R outside the instrument. To the sight is attached a telescope, omitted in figs. 1 and 3, but shown in figs. 7, 8, and 9 (pages 61, 62). This telescope is made to slide in and out, and is provided with a sun glass for use in adjustment, as described in fig. 6. The telescope (fig. 8) contains a double concave lens in the eye-piece, having the interior curves necessarily deep about 2½ inches radius upon account of the short focus. The object glass, which is composed of two lenses, would upon account of its long focus form an image at some distance outside the eye end of the instrument, but it is intercepted by the concave lens, and a virtual erect image is formed within the tube situated between the eye lens and the object glass. The distance between these lenses is equal to the difference of the focal lengths of the object glass and eye lens. (See fig. 7, page 82.)

When, as in use at sea, you have to look through the plain glass with the telescope, the shades worked by the levers above described are absolutely necessary to be used, either together or separately, at the time of observation, but in ordinary land surveying work, they must be lowered through the aperture, which is closed by the sliding shutter, so as to be out of the line of sight when they are not required. The telescope also is found to be generally inconvenient, as it takes time to arrange for distinct vision, and is, therefore, usually removed as soon as the instrument is known to be in adjustment. When the telescope is removed, a sliding-plate, shown in fig. 1 (pages 55-57), takes its place, and the eye is guided by a small aperture in this sliding-plate opposite the fixed half-silvered glass. The vernier shown in fig. 3, and enlarged in fig. 5, enables the angles taken to be read to minutes. It will be observed that this vernier is the same as described by fig. 4 of diagram (pages 44-46). It is not necessary to have the index or vernier, when about to read an angle, placed at zero to start with, as the angle depends entirely upon the conjunction of the objects viewed, appearing as one in the glass B opposite the eye-piece, but when it is desired to close the box it is necessary to place the vernier scale somewhere near the zero point by means of the milled-screw, R, otherwise the curved rack will project, as shown at P, in fig. 3, and prevent the cover passing over it.

The mathematical proof given upon the plate showing figs. 1 to 5 (pages 55-57) will be seen to depend chiefly upon the facts stated at the commencement, and upon the principles enunciated in Euclid, that the exterior angle of a triangle is equal to the two interior and opposite angles, also that when two straight lines cut one another, the opposite angles contained by those lines are equal. Thus, we prove that the angle, A E B, is double the angle, A F B. Now, if the mirror at A be placed parallel to the mirror at B, the angle M A F will equal the angle A F B, and, therefore, the angle A E B will be double the angle M A F. Hence, if the vernier stand at zero upon the plate shown in fig. 3, when the mirrors are parallel to one another, the angle at E will be double the angle over which the revolving mirror will travel. Fig. 1 supposes a case in which this angle is 52½°, and hence the vernier in fig. 3 stands at 105°. The angle thus indicated in fig. 3 is not exactly vertically over that in fig. 1, but is made to depend upon it, the graduated silver arc being fixed in the most convenient position upon the top plate for recording the angles. A small magnifying glass is attached, as shown in fig. 3, which glass can be raised or lowered to suit the eyesight, enabling the subdivisions upon the vernier to be clearly defined. The surveyor selects the line which comes on his left hand when about to take an angle between two given directions, or to set out an angle in a required direction, and holds the instrument in his right hand by the box cover which has been screwed on to its underside after lowering the darkening glasses by means of the side levers as described. He then observes a pole marked D in fig. 1 (pages 55-57) through the unsilvered portion of the glass marked B, and with his left hand he turns the milled screw R until the pole marked C upon his right hand is reflected from the mirror at A to the silvered portion of the mirror at B. When these two poles appear in line one over the other in the glass B, as shown in fig. 2, the desired angle is obtained and read off the upper plate; or, when the angle is given, the surveyor directs his assistant to move the pole C right or left as required until set out to the given angle, as will be proved by the coincidence of the poles in the glass at B. To observe the pole D, the instrument is moved slowly by the right hand until its face is in the plane passing through the eye and the two objects between which the angular

BOX S

NOTE—WHEN AN OBJECT IS VIEWED AT AN INFINITE DISTANCE, AND THE
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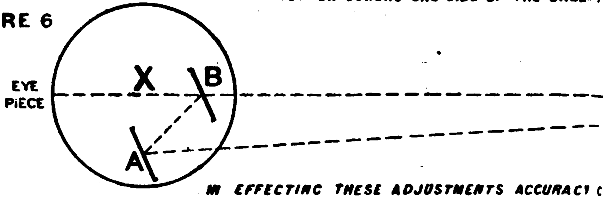
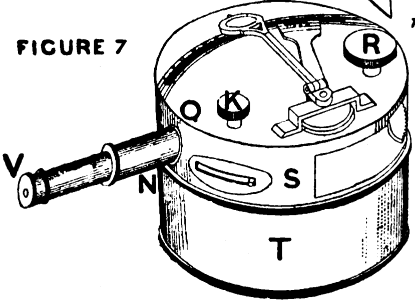
SCREW NEAR B WHICH RAISES OR LOWERS ONE SIDE OF THE UNDE

FIGURE 6



IN EFFECTING THESE ADJUSTMENTS ACCURACY
DISTANCE, IN ORDER THAT THE ANGLE FORMED BY LINES DRAWN
IN THE INSTRUMENT (BDA IN FIGURES 1-AND 3—) MAY BE AS NEA

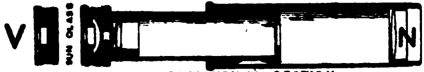
FIGURE 7



THE INSTRUMENT IS
NOT EMPLOYED.
THE TELESCOPE IS
AS SHEWN IN FIGU
THE LOWER PART
FIXED AT THE
LEFT HAND SIDE
THE SCREW
HAND SIDE OF THE
SEE FIGURE 2 —
MARKED T COVE

FIGURE 8

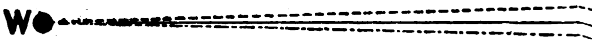
SLIDING TELESCOPE SHEWN IN FIGURE 7



—*LONGITUDINAL SECTION*—

NOTE—IN
TELESCOP
ATTACHM

FIGURE 10

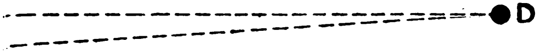


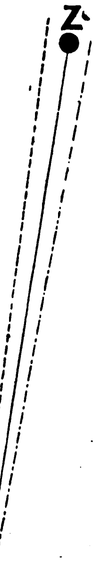
THE ADVANTAGE OF VIEWING TWO POLES Y. AND Z. IN THE LINE X.Z.
THE BOX SEXTANT IS HERE SHOWN.—THE INACCURATE POSITIO
THE POINT X. WHEN ONLY ONE POLE Z. IS VIEWED IN THE LINE X.Z.
(AS INDICATED BY THE DOTTED LINES)

[*Field Work and Instruments, pp.* 61 62

SEXTANT

NDEX OF THE INSTRUMENT IS SET AT ZERO THE GLASS **B** SHOULD BE PARALLEL TO
R **K**, (1) HORIZONTALLY, BY TURNING THE SQUARE HEAD OF THE SPINDLE **L**, WHICH
) TO ITS CONNECTION WITH THE UPPER PLATE—(2) VERTICALLY, BY MEANS OF THE
ER PLATE, TO WHICH THE GLASS **B** IS ATTACHED.———





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N FROM THE CENTRE OF THE OBJECT VIEWED, TO THE CENTRE OF EACH GLASS
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T OF THE INSTRUMENT MARKED **T**, IS HELD IN THE RIGHT HAND, AGAINST A POLE
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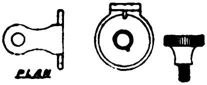
RKED **R**, IS TURNED BY THE LEFT HAND, UNTIL THE POLE **C**, SITUATED UPON THE RIGHT
THE SURVEYOR, IS REFLECTED OVER THE POLE **D** IN THE FIXED GLASS MARKED **B**:
:—— THE ANGLE UPON THE UPPER PLATE IS THEN READ.—WHEN CLOSED, THE CASE
VERS THE UPPER PORTION MARKED **S**———

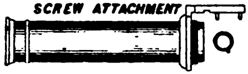
FIGURE 9



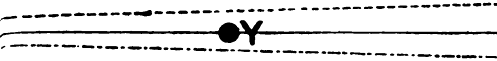
PLAN

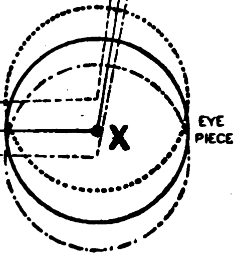
SCREW ATTACHMENT

IN SOME INSTRUMENTS THE
OPE IS CONNECTED BY THE
MENT MARKED Q IN FIGURE 8



TELESCOPE CLOSED SEE FIGURE 8



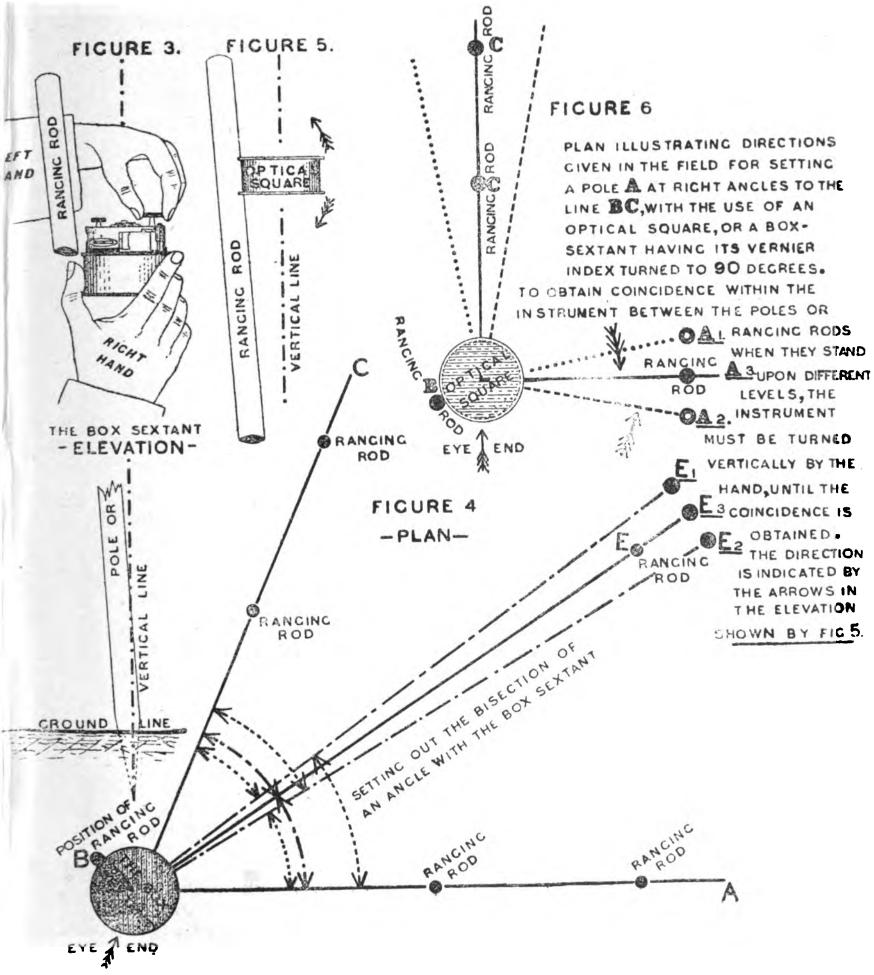


WHEN SETTING OUT OR READING AN ANGLE **ZXW** WITH
G IN WHICH THE INSTRUMENT IS LIABLE TO BE HELD OVER
C. LEADING TO INACCURACY OF DIRECTION IN THE LINE **XW**.—

distance is being taken. When, therefore, altitudes are to be observed, the instrument is held in a vertical plane; when horizontal or oblique angles are to be measured it is held in a horizontal or oblique plane. To ensure accuracy in the position in which the instrument is held the same precaution as to the use of double poles or ranging rods in a line is necessary to be observed, as was explained in the description of the optical square. This will be clear upon reference to fig. 10 (pages 61, 62). The adjustments of the mirror are effected by the key marked K in fig. 3 (pages 55-57), which, for safety, is screwed into the top plate, as shown in section in fig. 4, and which key should always be returned to its place of safety. These adjustments are usually made by the manufacturer, and when once effected, seldom need repetition, but may be tested by the surveyor in the following manner As shown in fig. 6 a distant object is observed with the vernier set to zero. If the sun be that object then the reflected image of the lower part of the sun will or can be made to appear vertically in line with the upper part of the sun by means of the key K slowly turning the bar L in the side of the instrument fig. 1, which acts upon the spring connexion shown in fig. 2. By this means the two mirrors are placed horizontally parallel; then by turning the instrument on its side and repeating the operation, but this time placing the key K in the spindle marked near B in the top plate (fig. 3) the mirrors can be set also vertically parallel.

When the objects observed are very close, the parallax of the instrument exerts an influence upon the value of the angle recorded. To allow for it, its amount should first be ascertained by placing the index of the instrument at zero and looking through the instrument at any horizontal surface, such as a window sill or top of a wall, which will appear as a broken line if influenced by parallax, when by turning the screw marked R, and thus moving the index to the left of zero until the broken line appears reunited, the small angle of excess which the box sextant then indicates will be the amount to allow for parallax.

The parallelism of the line of the sight in the telescope to the plane of the instrument is tested by placing the index glass so as to produce the apparent coincidence of two



PLAN ILLUSTRATING DIRECTIONS GIVEN IN THE FIELD FOR SETTING A POLE **A** AT RIGHT ANGLES TO THE LINE **BC**, WITH THE USE OF AN OPTICAL SQUARE, OR A BOX-SEXTANT HAVING ITS VERNIER INDEX TURNED TO **90** DEGREES. TO OBTAIN COINCIDENCE WITHIN THE INSTRUMENT BETWEEN THE POLES OR RANGING RODS WHEN THEY STAND UPON DIFFERENT LEVELS, THE INSTRUMENT MUST BE TURNED VERTICALLY BY THE HAND, UNTIL THE COINCIDENCE IS OBTAINED. THE DIRECTION IS INDICATED BY THE ARROWS IN THE ELEVATION SHOWN BY FIG 5.

distinct objects whose directions make an angle of 90° or thereabouts, and observing whether any slight motion of the plane of the sextant about an axis traversing the object seen by reflection disturbs the apparent coincidence. If the adjustment of the telescope is correct, no such disturbing influence should appear. We have mentioned this adjustment of the telescope to complete the subject, but as in ordinary land surveying the telescope is dispensed with, its accuracy when supplied by reliable makers can be trusted, and it is only necessary for the surveyor to test the adjustments described by fig. 6, an angle of zero degrees proving the correctness of the position of the mirrors. With constant use the mirrors will after some time get very dirty. The best way to clean them is by the use of a small light brush. For further explanation we refer our readers to the notes upon the plates (figs. 1-10, pages 55-57, and 61, 62).

The surveyor need not generally pay attention to the small error arising from parallax in a box sextant, but should great accuracy be required, and one of the objects be distant while the other is near, the parallax will be practically eliminated by observing the distant object by reflection and the near one by direct vision, holding the instrument for this purpose with its face downwards, if the distant object be upon the left hand. If both objects be near, the reflected image of a distant object in a direct line with one of the objects may be introduced, to be brought into coincidence with the direct image of the other object, and the parallax becomes eliminated. When both objects are distant the theodolite is the best instrument to employ. There is a certain amount of knack needed in the use of a box sextant to bring the two images in line apparently with one another, and the student is recommended to begin by placing objects at an acute angle with his eye, and he will find, with practice, that he can in time take angles up to 120° with facility. When the two objects are not situated exactly in the same plane, the surveyor will be obliged to incline the sextant to one side or the other, in order to obtain the necessary overlapping of the objects. In this case the angle taken, can be only approximately correct. This is one of the points in which a sextant is inferior to a theodolite. Flat country is most suitable for surveying with a sextant. Hence its application in the nautical sextant for use at sea (page 67).

Fig. 3 (page 64) shows the method of holding the box sextant over the point at the peg of intersection indicated in fig. 4, when taking the angle A B C. The value of the angle so obtained is, in the case of setting out curves by off-set measurements, off a tangent line, required in the first place to be bisected, and the direction of the line B E is set out by placing a ranging rod anywhere in the line B E, so that the angle E B A is half the angle A B C. The position of this line B E should be checked by setting out the line B E from the side B C. If any difference is found by this checking, in the position of the pole to be placed upon the line bisecting the angle, A B C, we have only finally to fix the pole E midway between the two points arrived at, after taking the half-angle separately upon each side of B E as indicated by the dotted lines in fig. 4. But when two poles are set up for view upon each of the lines B A and B C respectively, and the pole at B is carefully pulled upon one side out of the perpendicular, as shown in fig. 3, to enable the centre of the instrument to be vertically over the point B, and at the same time in line with the two poles viewed, the angle A B C may be taken with sufficient accuracy by means of a box sextant to obtain the half-angle correct enough for all practical purposes. The same remark applies also to the use of the optical square for setting a line at right angles to another line as shown in figs. 5 and 6.

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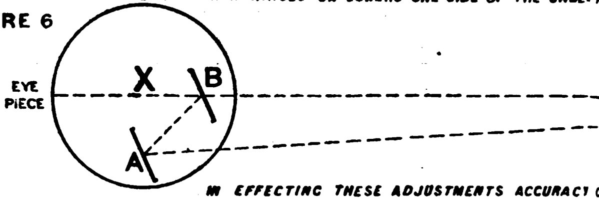

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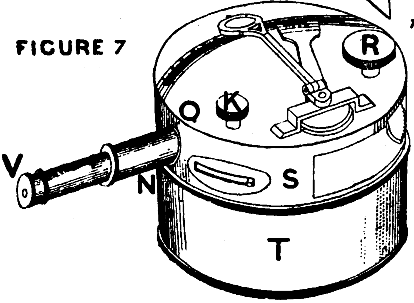

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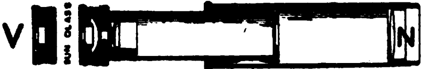
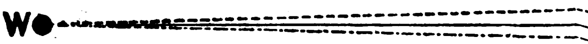


—LONGITUDINAL SECTION—

NOTE—
TELESCOP
AT TACHME

FIGURE 10



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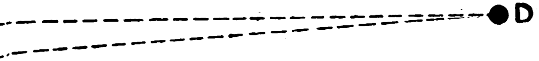

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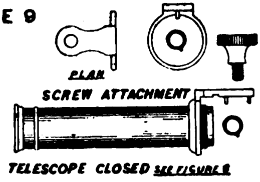
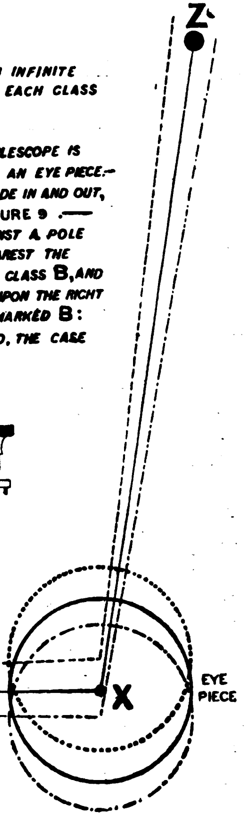
INTERSECTION OF THE TWO GIVEN LINES **DE** AND **CE**; THE POLE NEAREST THE
OF THE SURVEYOR, IS VIEWED THROUGH THE PLAIN PORTION OF THE GLASS **B**, AND
KED **R**, IS TURNED BY THE LEFT HAND, UNTIL THE POLE **C**, SITUATED UPON THE RIGHT
THE SURVEYOR, IS REFLECTED OVER THE POLE **D** IN THE FIXED GLASS MARKED **B**:
—— THE ANGLE UPON THE UPPER PLATE IS THEN READ.—WHEN CLOSED, THE CASE
VERS THE UPPER PORTION MARKED **S**———

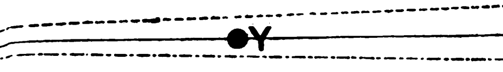
FIGURE 9



TELESCOPE CLOSED SEE FIGURE 8

†IN SOME INSTRUMENTS THE
OPE IS CONNECTED BY THE
MENT MARKED Q IN FIGURE 8



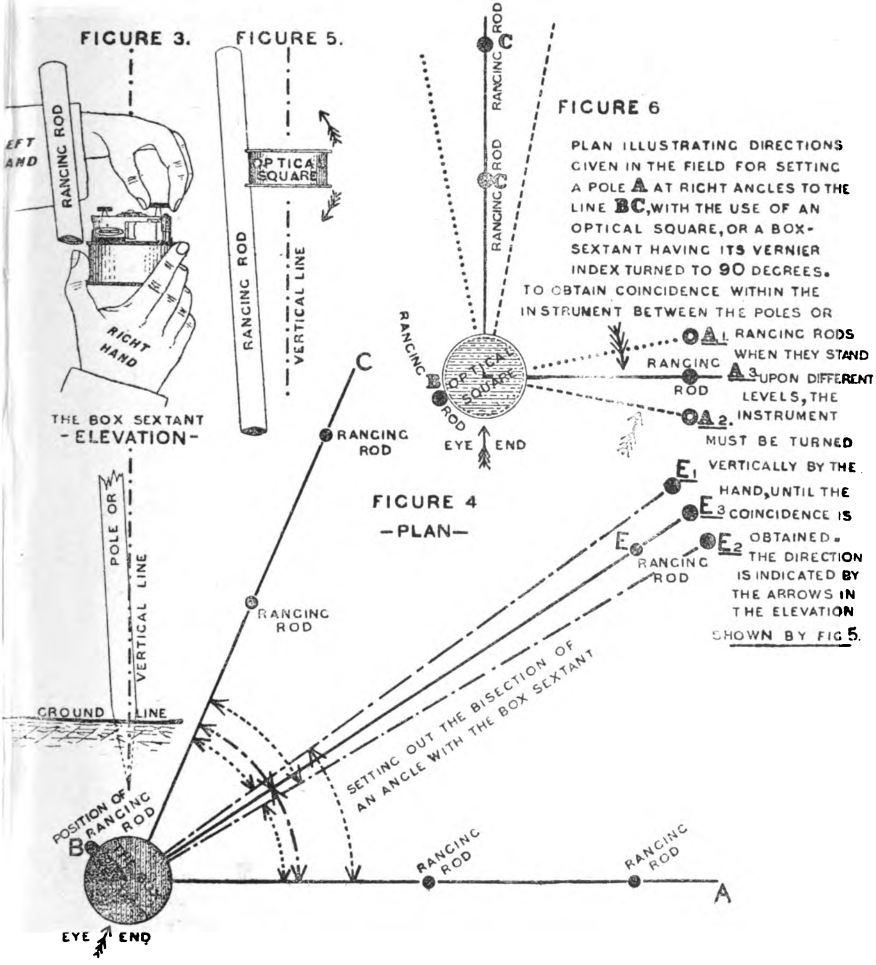


WHEN SETTING OUT OR READING AN ANGLE **ZXW** WITH
IN WHICH THE INSTRUMENT IS LIABLE TO BE HELD OVER
X'. LEADING TO INACCURACY OF DIRECTION IN THE LINE **XW**.—

distance is being taken. When, therefore, altitudes are to be observed, the instrument is held in a vertical plane; when horizontal or oblique angles are to be measured it is held in a horizontal or oblique plane. To ensure accuracy in the position in which the instrument is held the same precaution as to the use of double poles or ranging rods in a line is necessary to be observed, as was explained in the description of the optical square. This will be clear upon reference to fig. 10 (pages 61, 62). The adjustments of the mirror are effected by the key marked K in fig. 3 (pages 55-57), which, for safety, is screwed into the top plate, as shown in section in fig. 4, and which key should always be returned to its place of safety. These adjustments are usually made by the manufacturer, and when once effected, seldom need repetition, but may be tested by the surveyor in the following manner As shown in fig. 6 a distant object is observed with the vernier set to zero. If the sun be that object then the reflected image of the lower part of the sun will or can be made to appear vertically in line with the upper part of the sun by means of the key K slowly turning the bar L in the side of the instrument fig. 1, which acts upon the spring connexion shown in fig. 2. By this means the two mirrors are placed horizontally parallel; then by turning the instrument on its side and repeating the operation, but this time placing the key K in the spindle marked near B in the top plate (fig. 3) the mirrors can be set also vertically parallel.

When the objects observed are very close, the parallax of the instrument exerts an influence upon the value of the angle recorded. To allow for it, its amount should first be ascertained by placing the index of the instrument at zero and looking through the instrument at any horizontal surface, such as a window sill or top of a wall, which will appear as a broken line if influenced by parallax, when by turning the screw marked R, and thus moving the index to the left of zero until the broken line appears reunited, the small angle of excess which the box sextant then indicates will be the amount to allow for parallax.

The parallelism of the line of the sight in the telescope to the plane of the instrument is tested by placing the index glass so as to produce the apparent coincidence of two



THE BOX SEXTANT
-ELEVATION-

FIGURE 4
-PLAN-

FIGURE 6

PLAN ILLUSTRATING DIRECTIONS GIVEN IN THE FIELD FOR SETTING A POLE **A** AT RIGHT ANGLES TO THE LINE **BC**, WITH THE USE OF AN OPTICAL SQUARE, OR A BOX-SEXTANT HAVING ITS VERNIER INDEX TURNED TO 90 DEGREES. TO OBTAIN COINCIDENCE WITHIN THE INSTRUMENT BETWEEN THE POLES OR RANGING RODS WHEN THEY STAND UPON DIFFERENT LEVELS, THE INSTRUMENT MUST BE TURNED VERTICALLY BY THE HAND, UNTIL THE COINCIDENCE IS OBTAINED. THE DIRECTION IS INDICATED BY THE ARROWS IN THE ELEVATION SHOWN BY FIG 5.

distinct objects whose directions make an angle of 90° or thereabouts, and observing whether any slight motion of the plane of the sextant about an axis traversing the object seen by reflection disturbs the apparent coincidence. If the adjustment of the telescope is correct, no such disturbing influence should appear. We have mentioned this adjustment of the telescope to complete the subject, but as in ordinary land surveying the telescope is dispensed with, its accuracy when supplied by reliable makers can be trusted, and it is only necessary for the surveyor to test the adjustments described by fig. 6, an angle of zero degrees proving the correctness of the position of the mirrors. With constant use the mirrors will after some time get very dirty. The best way to clean them is by the use of a small light brush. For further explanation we refer our readers to the notes upon the plates (figs. 1-10, pages 55-57, and 61, 62).

The surveyor need not generally pay attention to the small error arising from parallax in a box sextant, but should great accuracy be required, and one of the objects be distant while the other is near, the parallax will be practically eliminated by observing the distant object by reflection and the near one by direct vision, holding the instrument for this purpose with its face downwards, if the distant object be upon the left hand. If both objects be near, the reflected image of a distant object in a direct line with one of the objects may be introduced, to be brought into coincidence with the direct image of the other object, and the parallax becomes eliminated. When both objects are distant the theodolite is the best instrument to employ. There is a certain amount of knack needed in the use of a box sextant to bring the two images in line apparently with one another, and the student is recommended to begin by placing objects at an acute angle with his eye, and he will find, with practice, that he can in time take angles up to 120° with facility. When the two objects are not situated exactly in the same plane, the surveyor will be obliged to incline the sextant to one side or the other, in order to obtain the necessary overlapping of the objects. In this case the angle taken, can be only approximately correct. This is one of the points in which a sextant is inferior to a theodolite. Flat country is most suitable for surveying with a sextant. Hence its application in the nautical sextant for use at sea (page 67).

Fig. 3 (page 64) shows the method of holding the box sextant over the point at the peg of intersection indicated in fig. 4, when taking the angle A B C. The value of the angle so obtained is, in the case of setting out curves by off-set measurements, off a tangent line, required in the first place to be bisected, and the direction of the line B E is set out by placing a ranging rod anywhere in the line B E, so that the angle E B A is half the angle A B C. The position of this line B E should be checked by setting out the line B E from the side B C. If any difference is found by this checking, in the position of the pole to be placed upon the line bisecting the angle, A B C, we have only finally to fix the pole E midway between the two points arrived at, after taking the half-angle separately upon each side of B E as indicated by the dotted lines in fig. 4. But when two poles are set up for view upon each of the lines B A and B C respectively, and the pole at B is carefully pulled upon one side out of the perpendicular, as shown in fig. 3, to enable the centre of the instrument to be vertically over the point B, and at the same time in line with the two poles viewed, the angle A B C may be taken with sufficient accuracy by means of a box sextant to obtain the half-angle correct enough for all practical purposes. The same remark applies also to the use of the optical square for setting a line at right angles to another line as shown in figs. 5 and 6.

CHAPTER IX.

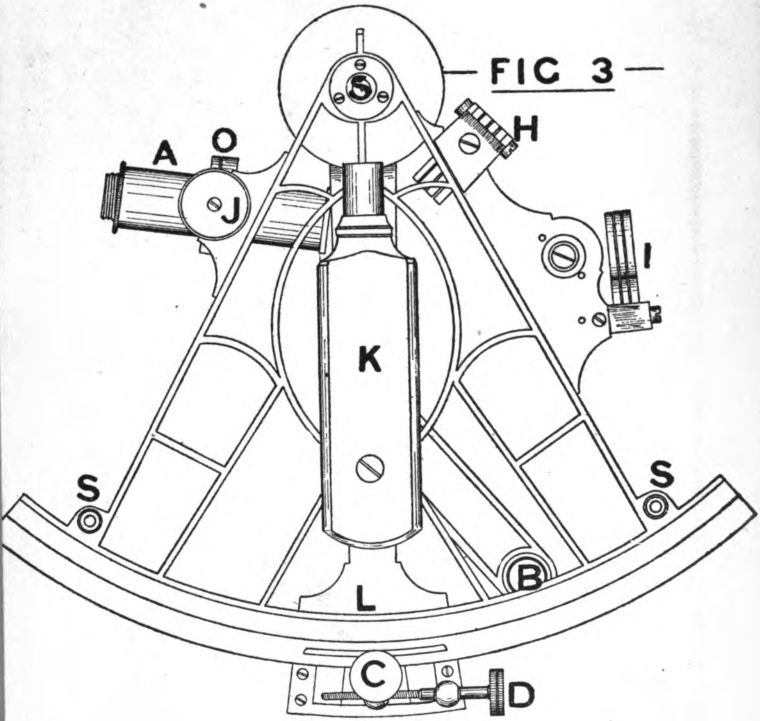
THE NAUTICAL SEXTANT.

THE Nautical Sextant (figs. 1-3, pages 68-70), is usually made in the form of the sector of a circle of about 60° in angular extent, S S S (fig. 3), but records angles upon the graduated limb (fig. 1) up to 120°. The instrument is so framed as not to be liable to bend. An arm carrying an index L, and bearing a vernier scale to the divisions on the arc, is attached to, and works round the centre S; a microscope, B, is appended for reading the divisions. At the back of the instrument is a clamp screw, C, for temporarily fixing the index arm in any required position, and outside the arc, at D, is a tangent screw for imparting a slow motion when setting the instrument. A mirror, G, is fixed upright on the edge, and, being attached to the radiating index arm, is called the index glass. The mirror fixed at E, which is half silver and half plain (see fig. 2), is termed the horizon glass. In the latter mirror (E) the unsilvered half is the farthest from the face of the instrument. Both mirrors have their reflecting surfaces accurately at right angles to the face of the instrument. A telescope, A, carried by a ring, O, is directed towards the horizon glass. The object of the up-and-down piece in which it works, is to vary the proportions of the light reflected from the silvered glass G, and through the unsilvered part of the horizon glass E, so as to produce an equalisation of brightness, which will be found to assist an accurate observation of angles.

For altitudes, the instrument is held by the handle K in the observer's right hand, circle down, and placed with its face as near as possible in the plane passing through the eye and the two objects, between which the angular measurement at the eye is required. For

[*Field Work and Instruments, pp.* 68, 69 70.

FIG 3



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horizontal observations it is held in a horizontal plane, and if needed for oblique angles in an oblique plane. The zero of graduation upon the limb is placed so that the index of the vernier shall indicate zero when the two mirrors should be parallel to each other. To ascertain this, set the zero on the index to zero upon the graduated arc, and direct your observation to the most distant object that can be clearly seen, in order to reduce the deviation from parallelism between the direct and reflected rays to a minimum. If the image reflected from the silvered glass G does not appear to coincide with the direct vision through the unsilvered part of the horizon glass E, the quantity of their deviation constitutes what is called the index error. The arm is adjusted until the two images coincide, and the graduated arc subsequently read. Should the index now point to the left of the zero, *i.e.*, on or within the arc, it shows that the angle recorded is too large by the amount between the index and the zero upon the arc, but should the index point to the right of zero, *i.e.*, off or without the arc, the angle read will be too small when the images coincide, for at the point where the index is when the two images coincide the graduation ought to commence. The graduated limb of a sextant is usually divided by a vernier to read to 20 seconds in a small instrument, and to 10 seconds in a larger size. H and I are sets of coloured glasses, technically called "darkening glasses," for use as shades when it is required to moderate the light from any bright object, such as the sun, which might prove too dazzling for view with the naked eye. When both the reflected and direct images require to be shaded, as would be the case when the sun's diameter is measured, and his altitude is desired to be taken with reference to an artificial horizon, the dark glasses near the eye-piece should be used without applying the other dark glasses.

The reflecting circle (figs. 5 and 6, pages 68-70) is an ingenious contrivance to secure accuracy of observation, devised by the late Mr. Troughton, sen. It is similar in principle and use, to a large sextant, but has three branch vernier readings, LLL, moving round the same centre as the index glass G, which is upon the opposite face of the instrument.

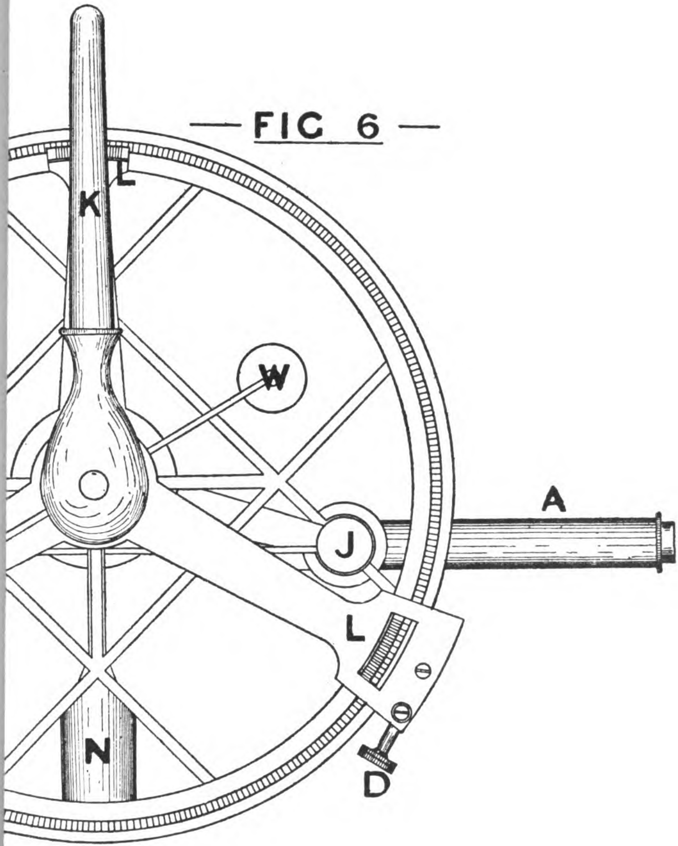
The limb forming a complete circle, the three index arms are made to radiate at angles of 120° from the centre G. The instrument is prepared for observation by screwing the telescope A into its socket O, and then holding the circle by the short handle N, adjusting the drawer to focus exactly the same as with a sextant, the surveyor directs the telescope to the fainter object and makes the contact in the usual way. Then he reads off the degrees, minutes, and seconds recorded, not only by that branch of the index to which the tangent screw D is attached, but also the minutes and seconds shown by the other two branches. The average result would serve to diminish some of the errors of manufacture, but by measuring the same angle of observation in the other three arcs, and taking the mean of six results obtained with the use of three verniers of the instrument in two positions, the errors become practically eliminated. The additional three observations are obtained by reversing the plane of the instrument and holding it by the opposite handle K, making the contact as before. Thus by observing both forwards and backwards with this instrument, if the true angle is increased by one way of observation, it is diminished the other way by the same amount, and hence not only need the ordinary index error be neglected, but the contribution to error produced by the different glasses is also corrected, and any geometrical error in the setting of the centre of the instrument becomes also obviated by reading the three branches of the index LLL.

The foregoing instructions for taking angles apply equally for taking altitudes by the sea or any artificial horizon, these altitudes being recorded as angles in a vertical plane. Meridian altitudes cannot, however, be taken both backwards and forwards in the same day, because there is not time at noon. All that can, therefore, be done is to observe the altitude one way, but even then you have the advantage of a mean of that altitude by the use of the three combined different verniers. Both at sea and land, when the observer is stationary, the meridian altitude should be observed forwards one day and backwards the next, and so on alternately from day to day, the mean altitudes deduced from such observations giving the true amount.

[*Field Work and Instruments, pp.* 73, 74, 75.

RCLE.

— FIG 6 —



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CHAPTER X.

THE LEVEL STAFF.

THE best constructed form of level staff consists of three rectangular parts sliding one within the other in a telescopic fashion. This form was first introduced by Mr. Gravatt, and subsequently improved by Mr. Bramah, Mr. Sopwith, and others, each varying the mechanical arrangements, but all agreeing in the provision of a sufficiently distinct graduated face for a surveyor to read off the height at the eyepiece of his instrument. Vane staves were in general use before the introduction of graduated staves and the dumpy level. The sliding vane provided a conspicuous object on a vertical staff which could be viewed by an observer and moved up and down until adjusted as required. The surveyor set up his level, and having adjusted the telescope horizontally, he looked through it at the staff, signalling the assistant to raise or lower the vane until a cross-line or central spot in the vane was visible through the centre of the telescope, and the height above the ground at the time the mark in the vane was level with the line of sight was then recorded. The sliding vane or cross-piece having to be repeatedly shifted to different heights was an anxious and tedious process, and was apt to drop while booking its reading. In the telescopic pattern the raised portions are maintained at the correct height by spring clips, and care must be taken in the field to observe that these clips properly rest upon the top of the lower piece at the back of the staff, otherwise the heights derived from the upper and middle portions will not be correct. When properly opened out for use, a staff is either 14ft., or 16ft., or 17ft. in length. If a staff of the latter length is adopted, the surveyor frequently avoids pulling up the top length during the prevalence of any wind. After working in the rain, the staff should never be immediately closed up, but should be disconnected and the three parts allowed to dry separately, otherwise the wood would warp, and great difficulty would be experienced in subsequently opening the staff to its full length.

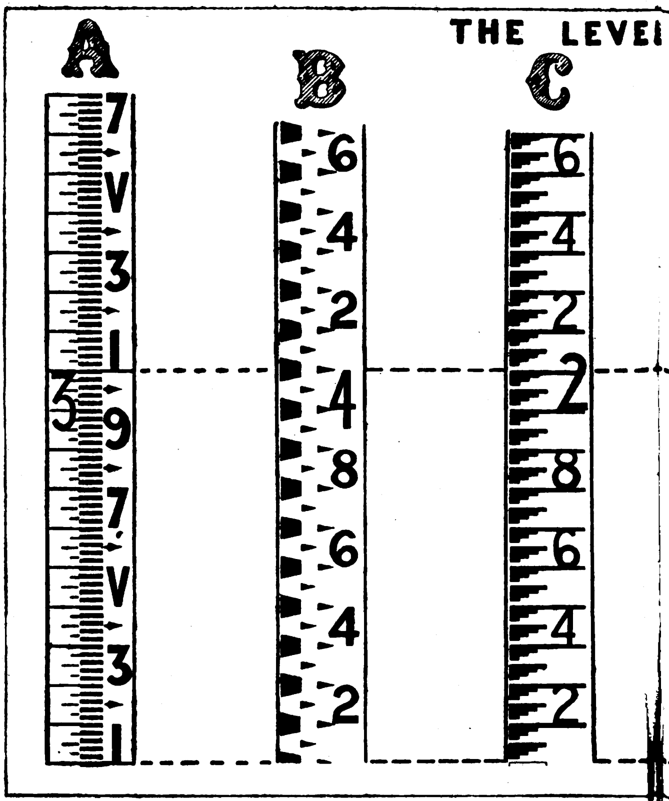
A level line is not a horizontal line, but one parallel to the surface of the earth, and forms a great circle radiating from the earth's centre.

Before proceeding to describe the optical instruments employed for taking levels, it is necessary to be acquainted with the graduations of a level staff, by means of which heights are read. Six different kinds of graduations are illustrated in our diagram (pages 79-80). The vertical distance between the two horizontal dotted lines indicates a height of one foot decimally divided. By placing a straight-edge across in any position parallel to these dotted lines, the reader will be able to compare the patterns A, B, C, D, E, and F, and to select the one he would prefer for use in the field. It will be observed in forms A and F that the odd tenths are numbered. In the diagonal pattern, B, the even tenths are numbered, but between decimal eight and decimal two of the next foot the only number is that indicating feet. These are generally in red figures. In forms A and F every alternate tenth division is seen to be numbered. In form B there is an evident ambiguity in reading decimal nine with its subdivisions; otherwise the diagonal pattern gives sharp definition. It is well to have the red figure for 9 feet filled in to avoid mistaking it for 6 feet, or *vice versâ.*

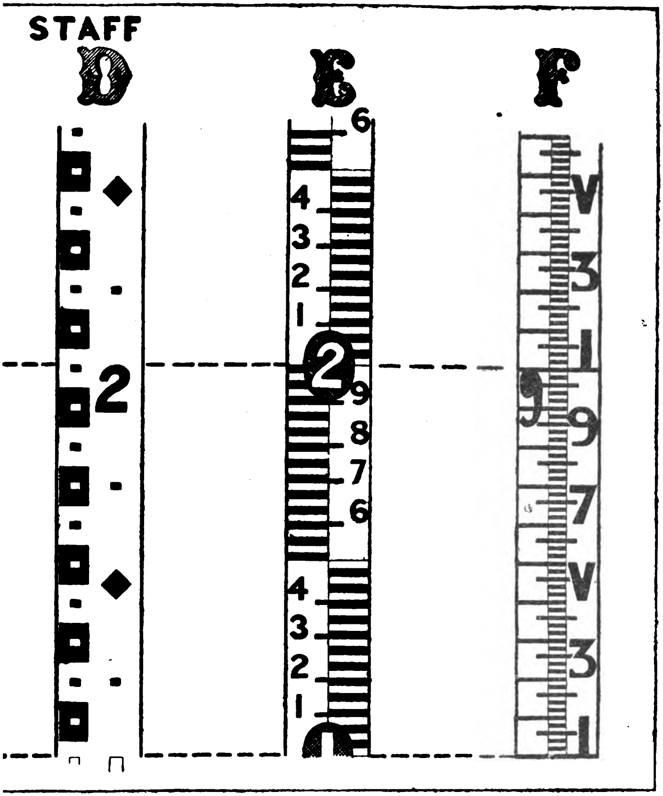
For convenience of carrying the level staff when travelling it is often strapped to the tripod or level-legs, but care must be taken that the staff is not scratched by the edge of the cap or by the rings which bind the tripod legs together. To obviate this, it is found useful to have a strip of wood, in the form of a straight-edge, made to fit the face of the staff, and to place it between the face of the staff and the folded tripod when they are tied together for transit. Another and more general plan is to have two pads of thick leather with rectangular holes pierced near their outer edges for a strap to pass through them, and thus bind the staff and tripod together in two places, with the leather pads packed between them. Great care should be exercised not to misuse a level staff. It should never be employed as a jumping-pole.

The Sopwith pattern shown in Form F is easy to read. Form D, known as Mr. Rogers Field's pattern, needs the eye to be specially trained before the divisions can be read with precision. Form C shows Mr. Stanley's pattern. It will be observed that the large figures indicating feet are deeper than the figures indicating tenths. In Forms A and F these figures indicating feet are placed upon the opposite side of the subdivisions indicating hundreds and tenths which read from the bottom upwards, and that the latter are made the full depth of the subdivision they indicate. Thus no ambiguity between the number of feet to be recorded and their fractional parts is likely to occur. Papered level staves are seldom correct, as the paper stretches upon application to the staff.

The reading furnished by the level staff when viewed through a telescope gives the apparent or optical level. The lines of collimation which determine the divisions upon the staff to be recorded are parallel to lines which are tangential to the earth's surface. A level line being one in which every point is equidistant from the centre of the earth, the surface of still water presents a level, but not a flat surface. Certain variations arising from the shape of the earth being a spheroid instead of a sphere we need not here enter upon, but, taking the mean diameter of the earth, *i.e.*, the average between the polar diameter and the diameter taken at the equator as 7,916 miles, it is evident that the convexity of the surface of water is so slight, as to escape notice, unless the clear open distance is great, as in the case of observing ships approaching one another at sea. A level line one mile in length is raised or convex in the middle to the extent of about four inches, and the distance between the true and apparent level is always proportional to the square of the distance over which it is measured. In ordinary surveying, the surface of the earth may be considered a plane, a degree of 69½ English miles not exceeding its chord by more than 25 ft.


THE LEVE
A
B
C
V
V

[*Field Work and Instruments, pp.* 79, 80.



CHAPTER XI.

SURVEYING TELESCOPES.

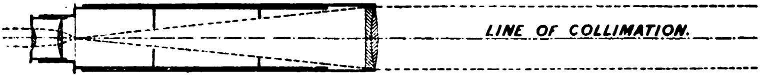
HISTORICAL records inform us that while the telescope was made use of as early as 1608, it was not applied as an accurate measuring instrument until Gascoigne, a young Englishman, in 1640, and Picard in 1669, placed in the focus of a telescope spider lines to mark the optical axis. Figs. 1 to 7 (page 82) illustrate the ordinary forms of telescopes used in field work, the geometry connected with the various forms of lens employed being explained in treatises on optics. Figs. 1 to 5 apply to a level through which a level staff is read, and the cone of rays formed in each case between the eye-piece and the object-glass is shown by dotted lines upon this diagram. Figs. 1 to 4 result in parallel rays, while in fig. 5 the rays from the object-glass outwards are seen to converge slightly. The position of the staff or object viewed is not shown, because to be correct, in figs. 1 to 5 it should be placed beyond the limits of the diagram. In the terrestrial eye-piece, No. 6, the diaphragm having to come near the eye lens, the focal length of the latter is three times shorter than that of the field lens. In fig. 7, radial lines outwards from the eye-piece meet in a point which must be within the focal length of the object-glass, or upon the telescope side of the point on which the dotted lines shown, meet outside the eye-piece.

Having carefully set up the instrument, the eye-piece must be first adjusted for *parallax*, a term derived from the Greek *παρά* (para), beside, and *ἀλλάσσειν* (allassein), to change or alter a little.. A parallax is likely to lead to an inaccurate reading or observation, and can be detected when the observer moves his eye up and down or sideways when looking through the telescope,

SURVEYINC TELESCOPES.

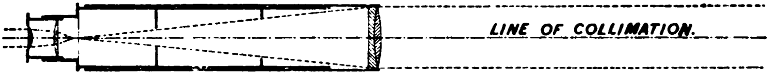
FIC.I.

FIC.I.2.3.SHOW THE ADJUSTMENTS OF THE EYEPIECE TO OBVIATE PARALLAX.



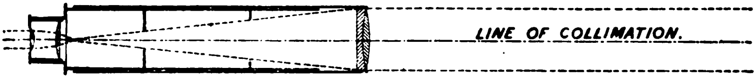
IN FIC.I.THE EYEPIECE IS CORRECTLY FOCUSSED AND PARALLAX IS OBVIATED. PARALLEL RAYS FROM OBJECT CLASS TO OBJECT VIEWED

FIC.2.



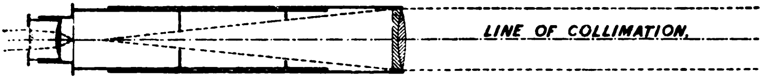
IN FIC.2.THE EYEPIECE IS TOO MUCH OUT, AND PARALLAX EXISTS

FIC.3.



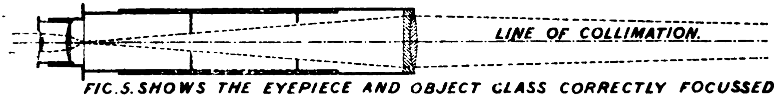
IN FIC.3.THE EYEPIECE IS TOO MUCH IN, AND PARALLAX EXISTS.

FIC.4.



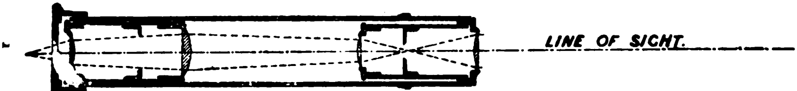
IN FIC.4.THE EYEPIECE IS CORRECTLY FOCUSSED, BUT THE OBJECT CLASS REQUIRES FOCUSSINC FOR THE DISTANT OBJECT:-IT IS CORRECT AS IN FIC.5, FOR A NEAR OBJECT

FIC.5



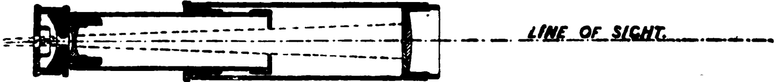
FIC.5.SHOWS THE EYEPIECE AND OBJECT CLASS CORRECTLY FOCUSSED FOR A NEAR OBJECT:-RAYS SLICHTLY CONVERCE TOWARDS OBJECT VIEWED.

FIC.6



FIC.6.SHOWS THE LONC OR ERECT EYEPIECE ATTACHED TO A "THEODOLITE."

FIC.7.



FIC.7.SHOWS THE TELESCOPE ATTACHED TO A "BOX SEXTANT."

the point viewed being unaltered by a slight vertical or lateral movement of the eye. When the image of the object viewed, formed by the object-glass, either falls short of or beyond the place of the cross hairs, the error arising from this cause is termed parallax, and the purpose of the adjustment is to make the focus of the eye-piece coincide with the focus of the object-glass. If this adjustment is perfect, the image of the object viewed will appear to coincide with the cross hairs, when the eye is moved backwards and forwards. If imperfect, the image will appear to waver when the eye of the observer is moved. When the image appears to shift in the opposite direction to the head, the eye-piece must be drawn out a little farther; when in the same direction, the eye-piece must be drawn a little inwards. So long as the eye-piece remains undisturbed, the process need not be repeated for the same eye, but would in all probability need alteration to suit the eye of another person. The position of the object-glass with reference to the eye-piece will need alteration at every change of distance of the object viewed. The focus of a large lens is always a small circle—not a point, as indicated in the diagram (page 82)—but no real image can be formed, as there is no screen to receive it. The rays simply meet at a point called the focus, and proceed on their course through the several lenses composing the eye-piece. The rays are always turned out of the eye-piece parallel to one another, and then the eye of the observer focusses them upon the retina. The rays between the object-glass and the object viewed slightly converge towards a near object (fig. 5), but the more distant the object the more parallel do these rays become. The use of the shade cylinder in the field with its cover over the object-glass serves to keep out a large amount of rain when working with an instrument in wet weather. The shade cover is merely opened when taking a sight through the telescope, and immediately closed as soon as the sight required is taken. The eye-piece may also be fitted with a small shade cover, but the usual plan is to cover it with the thumb-stall or finger stall of a kid glove when not observing a sight, during the visitation of rain.

An object-glass may be formed of two or more lenses of different kinds of glass, viz., flint and crown, having different powers of refraction, so as to correct the dispersion which an unequal refraction would produce. Two lenses are the most common, the number employed depending upon the circumstances of focal length and aperture. Both the dispersive and refractive properties of the lenses have to be considered by the maker. Three lenses are considered to provide the most perfect achromatism, consisting of a double concave centre of light flint glass with outside convex surface of green crown glass held together and encircled by a thin brass ring, over which an outside brass ring is fitted. (See page 88.) One advantage of the use of three lenses in an object-glass is that the outside lenses protect the central flint glass portion and prevent it becoming stained and tarnished. A flatter surface can also be given to the lenses when three are employed, and a sharper definition of the object viewed provided. The lenses must have a common axis. The axis of the telescope should be parallel with the axis of the cylindrical pieces in which it is held in the Y's, but the exact coincidence of the cross hairs with the axis of the telescope is not absolutely essential to correct levelling.

Atmospheric refraction is an optical deception or apparent displacement of an object. Mr. Butler Williams, in his treatise on "Practical Geodesy," thus describes the effect of refraction:—"Experience has shown that rays of light in passing obliquely from a medium of a given density change their direction, and approach more nearly to that of a perpendicular raised to the common surface at the point where they enter the denser medium. Now the atmosphere increasing gradually in density from its external limits to the surface of the earth may be supposed to consist of successively superposed minute layers, each concentric with the general surface of the sea, and each of which is more rarefied, or specifically lighter, than that immediately beneath it, and denser, or specifically heavier, than that immediately above it. A ray of light, therefore, passing obliquely through the atmosphere, for example, from a higher to a lower level, to the eye of an observer passes from the rarer to the denser strata; and following the above law of optics, it will be diverted from its original course and made to approach more and more nearly to a perpendicular to the horizon. It will thus describe a curve concave to the earth's surface; but it is a law in optics that an object is seen in the direction which the visual ray has, on arriving at the eye without regard to what may otherwise have been its course between the object and the eye; the object appears, therefore, in the direction of the tangent to this curve. Every difference of level, accompanied as it must be with a difference of density in the state of the atmosphere, will have corresponding to it a certain amount of refraction; and as the curve described by each ray of light is concave next the earth, the tangent to the curve will lie above it, and consequently the object will appear more elevated above the horizon than if there were no atmosphere." Thus the sun may be seen above the horizon after it has really sunk beneath it, because the nearer an object to the horizon the greater the refraction. (See page 180.)

The cross-hairs consist of single threads of a spider's web placed in a sliding frame forming a diaphragm, the cross hairs being cemented into the cuts upon the surface of a metal ring at right angles to each other. These spider's lines are extremely fine, and, at the same time, perfectly opaque. Other fine material is apt to be slightly fringed along its edge, and to cause confused vision when magnified. The diaphragm is fitted with capstan-headed screws for the purpose of adjusting it with the optical axis of the telescope.

The optical axis of a lens is the line joining the centres of the spherical surfaces by which the lens is bounded. The line of sight within the telescope is technically called the line of collimation, derived from the Latin, "collimare," for which the word "collineare" is now substituted, and signifies to direct something straight at a mark ("con" together, and "linea," line). This line forms the optical axis of the telescope, and joins the optical centre of the object glass with the intersection of cross hairs in a diaphragm plate, which are situated in the instrument at the common focus of the object-glass and of the eye-piece. In a theodolite the intersection of the cross-hairs forms the point for adjustment. In a dumpy level the horizontal cross-hair stretching across the axis of the telescope determines the plane of collimation. In adjusting the horizontal cross-hair so as to make the line of sight parallel to the run of the outside bubble, when set level, if we slack one of the vertical collimation screws slightly and to the same extent tighten the opposite one, we can adjust the horizontal cross-hair, so as to obtain accurate results in levelling, although the cross-wire may not traverse the axis of the telescope. Strictly speaking, each time the object-glass is removed this adjustment needs testing. Care must be taken that if the diaphragm is at any time removed, the same side of the ring is turned to the eye-piece as before it was taken out.

According to *Nature*, one of the simplest barometers is a field spider's web. When there is a prospect of rain or of wind, the spider shortens the filaments from which its web is suspended, and leaves things in this state as long as the weather is variable. If the insect elongates its thread, it is a sign of fine calm weather, the duration of which may be judged by the length to which the spider's threads are let out. If the spider remains inactive, it is a sign of rain; but if, on the contrary, it keeps at work during rain, the wet weather will not last long. Other observations show that the spider makes changes in its web every twenty-four hours, and that if such changes are made in the evening just before sunset, the night will be clear. The finest and cleanest webs suitable for diaphragms are those found on bushes in long grass. The common garden spider during the summer and autumn months spins his web in geometric patterns formed of thin cords. The house spider spins his webs in sheets, so that for telescopic work it is the garden spider we have to deal with. These webs may be transferred by bending a piece of wire in the shape of a two-pronged fork, with a space of 2 in. or 3 in. between the prongs, and turning it over in the hand while the spider is allowed to drop from one prong to the other, so as to collect the line of web formed by the spider in the fall, its weight being sufficient to stretch the line of web for insertion in the diaphragm. These webs can be readily affixed to a diaphragm plate in the proper position, as indicated by faint notches upon the metal, and a small plate acting as a washer-plate covers the aperture in the portion of the telescopic tube which holds the eye-piece in order to exclude dust. In theodolites it is generally considered to be more convenient when the tube carrying the object-glass end, moves away from the observer when focussing an object viewed by means of the side milled-head screw outside the telescopic tube than when, as in a level, the eye-piece end, usually travels towards him. Any way, the inner tube should travel in and out in a perfectly straight line in order that the line of collimation (see diagram, page 82), should be correct both for short and long distances. Any shake or looseness in the draw tube is prejudicial to accurate observation, especially in a level, and an experienced surveyor would pay special attention to this detail in selecting an instrument (fig. 3, pages 171-173).

The telescope is fitted with achromatic glasses, the object of which is to remove the indistinctness of vision which would be caused by chromatic aberration within the telescope. We know by experience that the rays of light, unless acted upon by some external cause, travel in straight lines, but that when a ray of light passes obliquely out of one medium into another of a different density, it becomes bent or refracted, as above stated, and its several component colours are separated and dispersed in a definite order, the red portion of the ray being the most refrangible and the violet, the least refrangible. A ray of light, in passing obliquely from the atmospheric medium into a lens, undergoes a compound deviation, known as spherical and chromatic aberration, which it becomes the business of an optician to remove in the production of an achromatic telescope. The spherical aberration is obviated by making the lenses of suitable shapes, and the chromatic aberration by re-uniting the colours, so that a colourless image may be formed at the focus within the telescope. The object-glass, fixed at the outside end of the inner tube, is made of a comparatively large size and of large focal length, in order that not only may sufficient light fall upon it to produce a distinct vision, but also that the rays of light may be the more accurately refracted. It is the property of convex lenses to diminish divergency, and of concave lenses to increase it.

When a ray of light passes from a denser into a rarer medium, the angle of refraction is greater than the angle of incidence; but when the ray passes from a rarer into a denser medium, the angle of refraction is less than the angle of incidence.

The colours, which are separated by the refraction of the first lens, are partly re-united by the refraction of the second or central lens, but the introduction of the third lens practically perfects the result, so that achromatic combination is produced, the dispersive effect of one glass being neutralised by the different density of the other glass or glasses.

After the lenses in the object-glass are adjusted in their relative position to one another, they are secured by the makers with a pin soldered within the cell which holds them. A notch being cut in the edge of each lens, the object-glass slides upon the pin, and is thereby guided and secured in its proper position. The outer ring is turned closely round the edge and burnished in a lathe. (See page 84.)

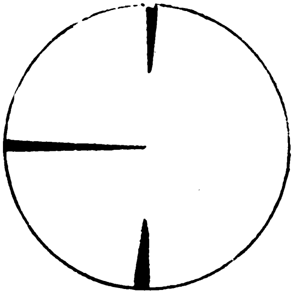
The eye-piece used is the Ramsden or positive eye-piece, consisting of two plano-convex lenses with the convex surfaces inside the eye-piece facing one another. The lenses are placed at a distance apart equal to half the sum of their focal length. In a positive eye-piece the focus lies beyond the lens which stands inside the telescope, and therefore a positive eye-piece is adapted for use with instruments having fixed spider's threads in the focus of the object-glass. In a negative eye-piece the two plano-convex lenses are placed with both the convex surfaces towards the object-glass, and hence the passage of rays from an achromatic object-glass after refraction in the glass of the eye-piece next the object-glass come to a focus within the eye-piece. When a negative eye-piece is introduced in a telescope, it inverts the image. The inversion of the level staff when viewed with a positive eye-piece is due to the way the rays proceed through the object-glass as explained in figs. 1 to 5 (page 82).

The lenses of a positive eye-piece (figs. 1 to 5) have equal focal lengths, f_1 and f_2, and if the distance between them is two-thirds of the focal length of either, and $a =$ distance between the lenses in a positive eye-piece of a dumpy level, then if the radius of the convex lens in the longer of the two eye-pieces usually provided with this instrument be $1\frac{1}{8}$ in., we have, by the principle of optics,

$$\frac{f_1\ f_2}{f_1+f_2-a}=\frac{f_1^2}{2f_1-\frac{2}{3}f_1}=\frac{f_1\times 3}{4}=1\tfrac{1}{8}\times\tfrac{3}{4}=\cdot 843$$

The convex lens in the shorter of the two eye-pieces for the same level would be $\frac{3}{4}$ in. radius, and hence $\frac{3}{4}\times\frac{3}{4}=\cdot 5625$. The latter eye-piece is generally preferred because it admits most light. (See fig. 2, pages 168, 169.)

If the curves of a lens be of unequal radii, the lens is said to be crossed, and the focal distance or distance of the focus from the nearest surface of the lens is found by dividing twice the product of the radii by their sum. The long eye-piece to a theodolite is not a combination of two eye-pieces, as might be thought upon inspection of fig. 6 (page 82), but a complete eye-piece in itself. The lens near the eye and also the third lens from the eye are both crossed. In many of the more expensive eye-pieces, the third is now a combination to overcome the effect of colour usually present in a long eye-piece.



In some surveying instruments the cross lines in the diaphragm are dispensed with, and iridium points projecting from a circular ring are (as shown in the diagram) introduced, which are stated to be better calculated for determining horizontal distances by perspective reading than with the use of a web which covers the line upon the staff, especially when observations some distance away have to be taken. Iridium is a metal, the most infusible and unchangeable of all substances except diamonds, osmium and ruthmium. It is very hard and very heavy, of a whitish colour, and is found associated with platinum. It is so named from the variety of colours of its compounds, and can be worked to a very fine point. Gold or platinum would prove too soft to work to points, and steel would be too easily corroded, but with platinum, iridium forms an alloy as elastic as steel.

Platinum wires are, nevertheless, frequently used in diaphragms. They are prepared by rolling platinum with silver, and drawing the combined metals to a very fine wire. The silver is then dissolved in nitric acid, which, having no influence upon the platinum, leaves the wire of this metal much finer than it could be made by merely mechanical means. Cross wires of floss silk are also sometimes employed. Glass diaphragms also have been tried, consisting of plain and parallel surface glass upon which fine lines are ruled. Away from a town or city where a mathematical instrument maker could not be found, except at a considerable distance, the possession of a diaphragm of this kind may be an argument in favour of its use, but a glass diaphragm is liable to become obstructed from "dewing," and the amount of light lost by the reflection and absorption of the glass plate gives to the ordinary open form of spider's web diaphragm a decided advantage. They can be attached to the metal plate with Canada balsam, common lac dissolved in spirits, or any gum moistened with diluted spirits. They are less affected by moisture than other substances, and it is difficult to procure this advantage in any material of sufficient fineness other than spider's web.

For cementing purposes in the manufacture of a surveying telescope, opticians obtain the oldest Canada balsam procurable, and drive off nearly all the essential oil left in it by long-continued moderate heat; the residual resin is then made slightly less brittle by dropping into it, when melted, an exceedingly small quantity of castor oil, taking at the same time special care not to add too much of the latter. The object sought is to obtain a transparent cement which will neither crack with age nor permit the formation of dendritical markings between the glasses from the evaporation of the oil employed.

The fine polish of the surface of an eye-piece and of an object-glass materially assists definition and brilliancy in a telescope. Hence attention should be given to keep both clean of dust and free from grease. Small particles of dust upon an object-glass do not prove so great an obstruction, however, as a thin imperceptible spot of grease or anything that would form a film over the surface of the glass. Each eye-piece may be removed, and may be taken to pieces for the purpose of wiping the glasses when needed for use in the field; but as will be observed upon examination of an instrument when the eye-piece of a theodolite or of a level is withdrawn, the diaphragm plate is totally unprotected, and great care must be taken not to touch or destroy the cross-hairs on wiping the open end of the telescope. The object-glass may also be taken out and wiped with a soft, well-used rag, not with silk or a piece of new muslin; and especially in instruments containing a magnetic needle should silk be avoided for wiping the glass covering the compass. Precaution must be exercised not to scratch the surface of a lens, and care taken to screw it back to the exact position which it occupied prior to removal, as its optical centre is assumed to have been set true by the makers when fixing it into the telescope. To effect this, it is well, upon receiving a new instrument from the makers, to scribe carefully a mark across the ring at the end of the inner tube to which the object-glass is attached, so that after removal it can be screwed back to its original position, the lines so marked being observed to coincide. Unless moisture has made its way in through the rim of one tube inside the other while focussing in damp weather, it is not necessary to wipe the surface of the inside of the glasses that are protected. Such moisture can best be removed by continually moving the inner tube of the telescope in and out, carefully drying it each time, with a cloth free from fluff until nearly all the moisture is removed, when the heat of a warm room free from draught will complete the drying, the inner tube being left for a time, drawn out with the eye-piece removed, and if moisture has gained access between the lenses, to take out the object-glass and wrap it up in a piece of blotting-paper, leaving it in a dry, warm place for a few hours before packing it away in the box. A leather outside case assists to keep the mahogany box, and consequently the instrument packed therein, dry. The usual strap accompanying a leather case should be made to pass through the side handles of the box, and a keyhole also made in the front of the leather case, so that it may not be necessary to remove the box from the case when removing or putting away the instrument.

When travelling it is well to place the instrument in its box under the seat of a railway carriage, where it is least subject to the oscillations of a moving train.

CHAPTER XII.

HAND LEVELS.

THESE instruments are of great service in preliminary work, or for arriving at an approximate comparison of levels in places where a larger instrument would be warned off. They commend themselves chiefly on account of their portability, as they can be easily carried in the pocket when not in use. Dr. Hooke was the first to apply an air bubble to an instrument for setting a line of sight in a horizontal direction. Fig. 1 (pages 94-96), which shows the longitudinal section of a reflecting level, illustrates the manner in which the detailed portions shown in fig. 2 are connected. B is an inner tube carrying half a convex lens. The reflecting-plate E occupies one-half of the interior of the tube to which it is attached underneath the centre of the spirit bubble K. The remaining half of the interior of the tube is left open to enable any distant point to be observed, the open and mirror portions being respectively placed upon opposite sides of a vertical diameter, as indicated in fig 2. The object seen when the bubble is in the centre of its run is, therefore, on a level in the line of sight, A D, with the observer's eye at A. A stop-piece is introduced to aid distinct vision, and is attached to the centre of the outer tube, as shown in fig. 1. It will be noticed that as no magnifying power is employed to observe distant points, the distance at which the divisions upon a level staff can be distinctly read is very limited, the only magnifying power within the instrument being the semi-circular convex lens, which magnifies the intersection of the horizontal line at E with the reflection of the spirit bubble.

In the employment of a hand level, it is useful to know the exact height of one's eye above the ground.

Fig. 7 illustrates a reflecting balance level hung upon gimbals. It is constructed upon the principle that a small mirror suspended vertically, when held at a short distance from an observer at the level of the eye, will reflect the pupil of his eye. As in the instrument previously described, a portion of the space is either open, or the glass is left plain, through which to view a distant object; and the eye of the surveyor is directed upon the line marked E across the silvered glass, so that when the reflection of half of the pupil of the eye is seen upon this line at the edge of the mirror, the observer is guided to read points at a distance in a horizontal plane upon a level with the eye. The height of the instrument from the ground, if required, is readily determined. In some instruments the mirror is fixed horizontally. In the illustration it is placed vertically. The instrument is held in the hand at arm's length by the ring H in fig. 7, and a level staff being held at any desired stations, such as F and G in fig. 6, first at one point, then at the other, with the instrument at the same level, the readings upon the staff can be compared in order to determine the rise or fall in the ground.

It is stated that Huygens in the seventeenth century was the first to apply a telescope to an instrument which was set level by means of a plummet. Later on, M. Le Bion combined the telescope of Huygens with the air bubble of Hooke. The inventor of the circular bubble is not known, but it is certain that it was employed in the early part of the eighteenth century upon surveying instruments known as plane tables.

In Captain Abney's level, illustrated by figs. 3 and 4, we have a reflecting level and clinometer combined. It consists of a spirit level so fixed at K to a limb carrying a vernier, that by turning a milled-edged wheel at the side of the telescopic tube as shown in plan in fig. 4, the vernier arm is made to move at right angles to the run of the bubble and upon the same transverse axis. The arc traversed by the vernier is graduated to indicate certain angles of inclination together with the corresponding ratio to the horizontal of the rise or fall of the gradient. The sight tube is divided horizontally in its interior by a glass,

NEY'S LEVEL

ELLIOTT PATTERN

LIMITING ANGLE 60°

FIGURE 3

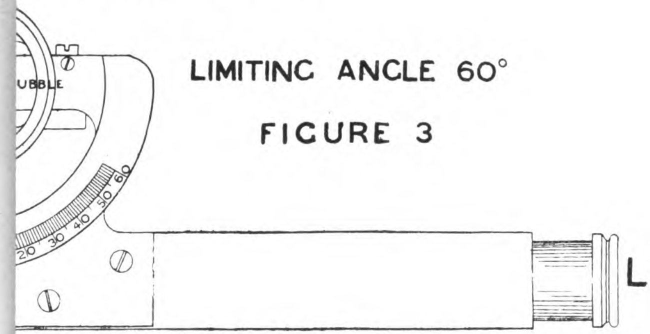


FIGURE 4

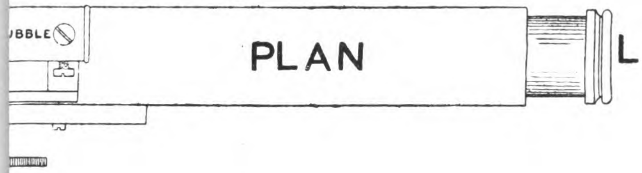
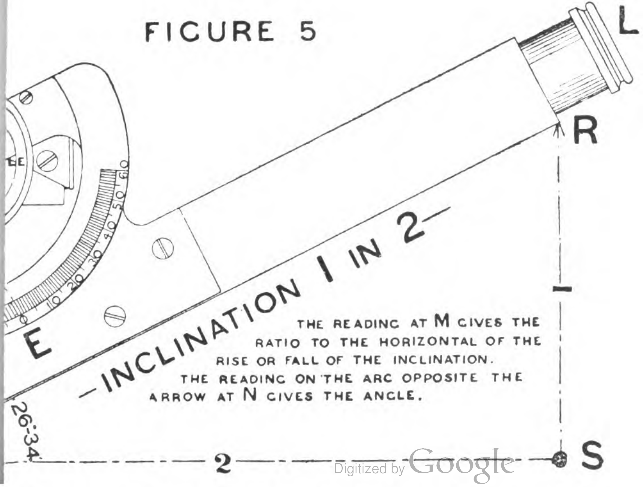


FIGURE 5



THE READING AT M GIVES THE RATIO TO THE HORIZONTAL OF THE RISE OR FALL OF THE INCLINATION.

THE READING ON THE ARC OPPOSITE THE ARROW AT N GIVES THE ANGLE.

'S LEVEL GIVING INCLINES

[Field Work and Instruments, pp. 94, 95, 96.

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ASTOR, LENOX AND
TILDEN FOUNDATIONS

half-silvered, fixed immediately below the bubble tube, in a similar manner to the detail shown in figs. 1 and 2, but the open portion in fig. 1 is in this instrument filled in with plain glass, so that the central horizontal line is marked across both the silvered and unsilvered portion of the glass.

To test the accuracy of the instrument, select two distant points, which shall previously be determined, upon the same level. Set the arrow-head upon the vernier arm to the point indicating zero upon the graduated arc, as shown at E in fig. 3, and look through the sight tube at the two points under observation. The bubble should then stand in the centre of its run, and be half reflected exactly upon the dividing line of the silvered portion of the glass. To arrive at the inclination or vertical angle of any given slope, the telescopic tube is held upon or placed parallel to the slope, as shown in fig. 5, and the side milled-edged wheel is then turned by the hand until the bubble appears in the centre of its run. The reading upon the arc at N will give the angle of the gradient. It will be seen that the angle R O S is equal to the angle E K N, and that if in fig. 5 the angle E K N equals 26° 34′, the vertical height R S will equal one unit at a distance, O S of two units from the point of observation.

CHAPTER XII.

UNDERGROUND SURVEYING.

THE magnetic needle without a check is not a safe guide in underground surveying. Ferruginous substances are plentiful in almost all mines—some visible enough, some, however, not visible to the senses of the surveyor. Such substances act upon the needle of the dial, and if no method be adopted to measure the amount of the attraction or to dispose of its erroneous readings, these surveys must be doubtful and worthless, and cannot be otherwise than a source of disappointment and, perhaps, disaster.

The Astronomer-Royal, in his "Introduction to Greenwich Magnetical Observations, 1886," states :—"In order to determine the effect of a mass of iron on the magnets, experiments were made on July 2, 1884, with 4, 8, 12, and 16 pieces of gutter respectively, placed at a distance of 25 ft. from the declination magnet in a direction south-east (magnetic) from it, so that the maximum effect would be produced. The following were the results for the deflexions of the upper declination magnet contained in the Royal Observatory :—

	MEAN DEFLEXION.	
	MIN.	SEC.
With 4 pieces of iron gutter . .	1	4
" 8 " " . .	2	2
" 12 " " . .	3	12
" 16 " " . .	3	40

Each piece weighed nearly 3 cwt.

As the effect of a mass of iron on a magnet varies as *the sine of twice its magnetic azimuth divided by the cube of its distance from the magnet*, these experiments show that the deflexion caused by the whole of the iron in the Lassell instrument and dome (which is at a distance of 100 ft., and very nearly in the magnetic meridian of the declination magnet) would be quite insensible." In commencing an underground survey, the Surveyor should not commence at the pit's eye, because it is next to impossible to get a true reading on account of substances of iron. Select some disused road (such are to be found in most pits) and take from two separate stations its magnetic bearing. If no disused road can be found in the pit, then take up the tram rails, say for 20 yards, and remove all other iron for the same distance, so that one magnetic bearing may be obtained without attraction. Register the bearing of the line joining the two separate stations selected with the line of the magnetic meridian by means of the vernier plate. Then in future readings, if the needle and vernier readings agree, there is no attraction. If they differ, the amount of magnetic attraction is the difference between the magnetic and vernier readings. The vernier reading must always be taken in preference to the magnetic, because it will be found in practice that, when there is no attraction, the magnetic and vernier readings will again agree—and this will be found the case throughout the survey, and give undoubted proof that the work is right.

To commence a survey without the magnetic needle in a mine possessing only a single shaft the following plan may be adopted. Attach fairly heavy weights to two thin copper wires, and suspend them from a beam placed horizontally across the upper surface of the shaft, and as close to the edges of the shaft as possible, so as to allow a man to pass, taking care that the weights reach very nearly to the base of the shaft, where they should be immersed in buckets of water to steady them, and so to diminish oscillation if the shaft is deep. The surveyor, standing behind the wires, next sends a man with a candle along the heading so as to fix it in a straight line with the wires. He then repeats the operation in the opposite direction, by placing a candle against one of the two wires, in order to check the direction of the line, by finding that the three candles are exactly in a line. This line then forms a base line of the whole underground survey, and is permanently marked by three or four pegs driven at intervals into the roof with nails in

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them to indicate the line, or by other approved marks. Upon each side of the shaft, at the level of the surface, permanent pegs are driven at some convenient distance apart to coincide with the direction of the wires, and the underground work is thus connected with the extended survey of the surface. A line is also obtainable by fixing two cross-beams at the top of the shaft from which to suspend two independent iron chains, with links about $\frac{3}{16}$ in. thick, and sufficiently long to reach from the top to the bottom of the shaft, by means of which chains, plumb-bobs, visible in the tunnel, are suspended in the shaft, as far apart as possible, without actual contact with the sides of the shaft. The vertical lines set out in a shaft enable the base lines in the tunnel to be connected with the base lines upon the surface of the ground, and hence, in the case of a single shaft, two lines are needed as far apart as circumstances allow.

The instrumental work required by surveyors for use in mining work, where the results of scientific knowledge and skill need to be as accurate underground as upon the surface, involves the question of transportation as well as of precise results. The instruments must be delicate in adjustment, and yet able to bear the wear and tear of a rough country. Heavy instruments are more liable than light ones to get out of adjustment in shouldering during the ordinary field service, and they expose a greater area to the wind. The weight should not, however, be reduced in the tripod, as a tripod too light destroys all the steadiness of an instrument.

CHAPTER XIV.

THE CIRCUMFERENTOR.

THE circumferentor is an instrument principally intended for subterranean surveying, but is also useful for completing the survey of any thickly-wooded portion of a country, where it is found difficult to connect the direction of any particular base line with the adjacent portion of the work. In its simple form it constitutes a miner's dial, consisting of a circular box containing a very sensitive magnetic needle, mounted upon a stand with folding sight-vanes, which can be raised perpendicular to the compass-box. In each vane there are slots and holes, one over the other, a fine line of silk, horsehair, or wire being strained down the centre of each slot, in a similar manner to the sight-vane of a prismatic compass, and the circular holes are each crossed by lines at right angles to one another, the intersection of which is used in ranging the opposite sight-vane in line with a distant station. These sight-vanes are alternate, the aperture serving as an eye-piece in the one, being exactly opposite the aperture by which the centre of an object is ranged in the other. With this instrument the direction of the roads and workings of a mine, or of a stream through a wood, may be roughly determined by a comparison with the magnetic meridian. In the prismatic compass, the needle was seen to be attached to the card upon which the degrees of a circle were graduated (pages 13-15). In the circumferentor, the needle revolves upon its bearing in the centre of the dial, and the divisions are marked upon the compass-box, as shown in fig. 2, which represents a plan of the instrument with the sight-vanes raised ready for use, as in fig. 1 (pp. 103-105). In fig. 5 the instrument is shown closed with a cover over the compass-box and the sight-vanes folded down for the convenience of packing. The needle in fig. 2 is released to play freely by pulling out the stop-piece marked M. The compass-box containing the needle is covered by a glass to exclude moisture, air, and dust. The forms of the needle are very varied. Some have the greatest breadth in the horizontal, others in a vertical direction. It is of primary importance that a surveyor should comprehend those points in the care of an instrument by which its usefulness may be preserved. In order to avoid dulling the centre pin, he should never lift the instrument, without being sure that the needle is clamped. Fig. 3, which represents a plan of the underneath portion of the instrument, shows the position of this stop-piece with reference to the set-screw H, which clamps the instrument to its stand.

The fixed divisions upon the dial in the compass-box are marked very distinctly upon a raised circular rim, which forms the outer edge of the silvered plate marked A, in the centre of which the needle is carried. These divisions are engraved consecutively to 360°, in a contrary direction to the figures upon the face of a watch, and are usually cut upon both the outer and the inner edges of the face of this rim, with the figures indicating the degrees placed in order upon a circle between them, as shown in fig. 2. Upon the inner portion of this plate, the letter N denotes the north, coincident with the line marked 360° upon the graduated rim, and the letter S, immediately opposite, denotes the south point upon the dial coincident with the line marked 180°. The plate over which the needle travels is further divided within the raised rim by cross lines at right angles to one another into four parts, each quadrant being semi-divided, and containing sub-divisions reading from zero at the points marked N and S, advancing in tens of degrees to 90° at the points marked E and W. The inner circle of divisions upon the raised rim enables us to read to degrees, the angle of intersection at the centre of the compass-box, between the direction of the needle pointing to the magnetic north over the line marked N and S upon the dial, and the line ranged by the sight-vanes, while the addition of the vernier—an enlarged view of which is given in fig. 6—enables us to record angles within three minutes, or one-twentieth of a degree. (See pages 103-105.)

The compass-box is connected with an exterior gimbal ring, the latter carrying the arms, upon the ends of which

[*Field Work and Instruments,*
pp. 103, 104, 105.

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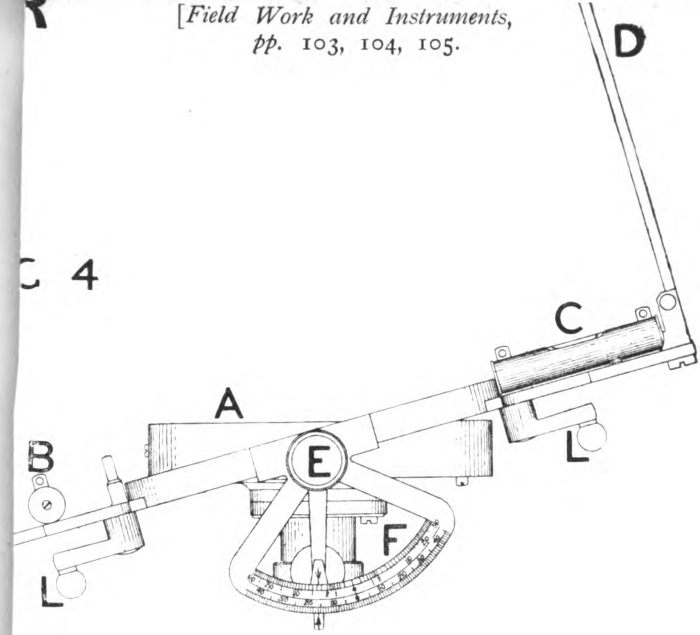

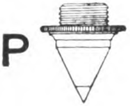

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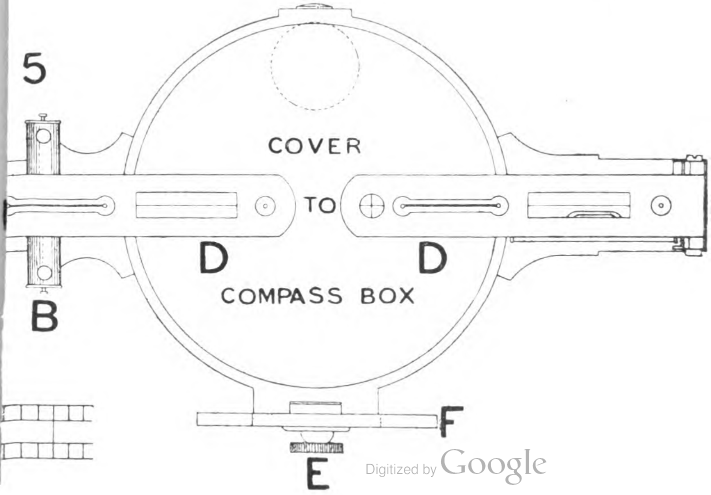

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the sight-vanes D D are attached. The best instruments have spirit-levels, B and C, fixed at right angles to one another upon these arms. The vernier is fixed to the inner edge of the box which holds the compass, its zero point being placed in the same vertical plane as the centre line of the sight-vanes, and in a line at right angles to the axis of the gimbal ring. A circular rack and pinion, worked by the milled screw K, shown in fig. 3, communicates to the vernier-plate an absolute horizontal motion round the outer circular rim of the dial-plate. By means of this rack-and-pinion movement great steadiness of action is obtained. The gimbal ring carrying the sight-vanes can be fixed rigidly to the compass-box by means of the turn stops L L, as shown in figs. 1 and 3, or inclined, as shown in fig. 4, when required to suit the declivity of a heading or tunnel. In fig. 4 it will be observed that the turn stops L L are unclamped by reversing. With the use of an arc marked F, which can be attached by the screw E, or removed at pleasure, the gradient of a heading may be measured, while the compass-box remains level, and records the magnetic bearing. Two scales of graduations are engraved upon this arc, one indicating the degrees of a circle between zero and 45°, while the other scale gives the corresponding values of the versines of the angles registered, these amounting to 1·52 in 100 for an angle of 10°, 6·02 in 100 for 20°, 13·4 in 100 for 30°, 23·4 in 100 for 40°, and 29·29 in 100 for 45°.

The compass-box is commonly mounted upon a ball-and-socket tripod, fitted with a turned and bored ferrule-joint. In this respect it differs from the screwed head shown in the illustration (pages 24, 25), of a ball-and-socket tripod stand which accompanied our description of the prismatic compass. In mining work it is found convenient to have the legs of the tripod jointed in the centre, as low headings often occur. When the legs are required to be shortened to suit the headway, three pegs each, similar to the one marked P in the diagram, are supplied in the box for screwing on to the middle portion of each leg, to obviate sliding when set up.

In order to find the bearing of a line by the circumferentor, place the instrument over the station point, with the gimbal ring clamped to the compass-box, as in fig. 1, and guided by the spirit bubbles, set it level by means of the ball-and-socket joint. The needle should be immediately released on setting the instrument, and there should be nothing carried by the surveyor to attract the needle, in the shape of penknives, watch-chains, large buttons, nor iron rivets in the magnifiers used to read the graduations; even watches containing nickel and the iron-wire brimmed edges of a felt hat should be avoided, as likely to produce an effect upon a sensitive needle when great accuracy is desired. If the circumferentor has no spirit levels attached, it may be set up approximately level by unclamping the needle, and noticing when it swings freely. Then turn the instrument round, so that the 360°, or point marked N upon the dial, is coincident with the marked or north end of the needle, and carefully make this coincidence, when the needle comes to rest, as accurate as possible by turning the milled screw K, which is situated below the compass-box, and hence shown dotted in fig. 2. Having done this, tighten the set screw H. Then by means of the milled screw K, turn the sight-vanes in the direction of the proposed line. Open, if necessary, the turnstops L L, and so place the sight-vanes D D that the centre of the object viewed is bisected by the cross hairs. The dial-plate being (as shown by the plan in fig. 2), open upwards, the divisions can be read entirely round the circle, and the miner's lamp can be held over the compass-box without disturbing the instrument (pages 103-105).

To adjust the compass, first bring the bubbles into the centre of their run by pressure of the hand upon different parts of the plate. Then turn the compass half-way round. Should the bubbles travel to the end of the tubes, it would indicate that those ends were the highest, and it would be necessary to lower them by tightening the screws immediately beneath, while loosening those under the lowest ends, until, by estimation, the error is half removed. Level the plate again, and repeat the first operation until the bubbles will remain in the centre during an entire revolution of the compass. The sights may be tested by observing through the slits a fine hair or thread made exactly vertical by a plumb-line. Should this hair line appear upon one side of the slit, the sight needs to be adjusted by filing off its under surface upon that side which seems the highest.

It will be observed, upon reference to the dial-plate in fig. 2, that in some instruments the right hand of the point marked N, when looking towards the north from the centre of the plate, is lettered west, and that the opposite point upon the left is lettered east. Thus the relative positions of east and west are reversed. The expression, the reverse bearing of a line, simply means that the bearing has been taken in a contrary direction; thus the reverse bearing of 34° east of north would be 34° west of south. It will, however, be found an advantage to maintain a uniformity of method in registering the angles, and always to book the relation that the magnetic north bears to the line of observation as recorded by the figured dial-plate. The process of "dialling a pit" is called by some "latching."

LEAN'S DIAL

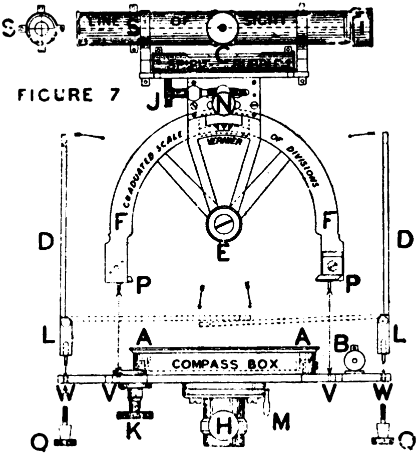


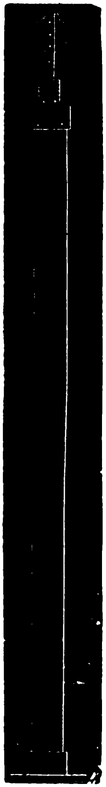
FIGURE 7

The efficiency of instruments to be used as circumferentors has of late years been improved in many ways. In Lean's miner's dial, illustrated by fig. 7, it will be observed, in the first place, that the gimbal-ring action, which was seen to be attached to the compass-box in figs. 1 to 5 (pages 103-105), is here omitted, and that the two side arms which carry the folding sight-vanes are permanently fixed parallel to the compass dial. The sight-vanes D can be removed and the direction ranged by a telescope, which traverses a vertical arc, marked F, above the compass-box, by which arrangement all vertical angles are measured. The addition of a telescope enables the surveyor to take longer and more accurate sights. The vertical arc consists of a flat metal ring about $\frac{11}{16}$ in. wide, $\frac{3}{16}$ in. thick, with pieces radial to its centre marked E, to which is attached a saddle body-piece carrying the telescope. Upon each face of the arc a scale of divisions is engraved; one scale shows vertical angles in degrees from zero to 90°, marked from about the centre outwards, the subdivisions being recorded by a vernier upon which an index-arrow registers the angle to be read. The vernier plate is attached to the traversing body-piece of the telescope. By means of an index-arrow marked upon a plate fixed at the back of this vernier plate, and which points to a scale upon the other face of the arc, the horizontal equivalent of any measurement taken along an inclined plane can be arrived at; the scale giving the difference between the hypothenuse and the base of a right-angled triangle in terms of the number of links to be deducted from one chain's length of 100 links, when measuring up or down a plane inclined to the vertical at the angle indicated by the scale of degrees marked upon the face of the arc first described. The difference arrived at by calculation would amount to 1·54 links in 100 links for an angle of 10°, 6·41 links in 100 for 20°, 15·4 in 100 for 30°, 30·5 in 100 for 40°, and 41·4 in 100 for 45°. The arc upon which the scales are marked gives the nominal size of the instrument. If the circle of divisions has a diameter of 6 in., this instrument would be called a Lean's 6-in. miner's dial. Both the sight-vanes D and the vertical arc F are each secured as required to the side arms of the compass-box by the set-screws marked Q, the sight-vanes being attached at the holes marked W, and the vertical arc at the holes marked V. The telescope can be clamped to the arc by means of the milled-headed screw marked N; the tangent screw, marked J, being intended for slow motion in final adjustment when the screw N is tightened. When the index attached to the sliding vernier stands at zero, the line of sight in the telescope (which joins the centre of the diaphragm, marked S, with the optical centre of the object-glass T) should be parallel to the dial in the compass-box, and when the telescope is so clamped, the compass-box can be set level by means of the long spirit bubble, marked C, which is fixed under the telescope, and the transverse or short bubble, marked B, upon the projecting arm of the compass-box. The divisions marked upon the tube at equal distances upon either side of the centre of the bubble serve to indicate very slight deviations from horizontality. The needle is set free by withdrawing the lever stop-piece M, and having set the N or 360° marked upon the compass-dial so as to coincide with the north point of the magnetic needle when at rest, the compass-box with the arms carrying the sight-vanes, or arc and telescope, may be made to turn round the dial by means of the milled head K of the pinion working the revolving gear.

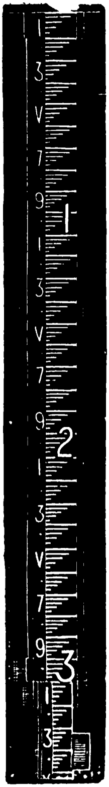
In Hedley's dial, which is so well known among mining engineers, by a special arrangement of the plates, the vernier is often placed on the outside circumference instead of inside the compass-box. The necessity of reading from above the dial face is thus obviated. The concentric action of the dial plates in this instrument may be tested by setting the needle and vernier to 360°, and then revolving the plates by means of the vernier screw and reading off the four quarters.

In the more expensive forms of circumferentors to which a telescope is attached, we find parallel plates sometimes substituted for the ball-and-socket head. These plates clamp the body of the instrument and are screwed on to the head of a tripod stand, the horizontal position of the compass-box being determined in setting up by means of one or more spirit levels so fixed as not to interfere with the action of the needle. In recording angles with a circumferentor, the surveyor reads the angle at the needle, and the graduations run to the left, as indicated in fig. 6, whereas in a protractor the graduations usually run to the right hand. Hence, when plotting, the needle is supposed to be at zero, and the direction of a line is plotted by means of the angle recorded by the instrument.

The pit levelling staff designed for underground levelling by Mr. George J. Jee, mining engineer, of Pontypool, to overcome the difficulty and inconvenience of using the ordinary form of levelling staff for underground work, consists of three lengths, sliding into each other, and nearly resembles the ordinary Sopwith staff in that respect. The bottom length is graduated upwards in the ordinary way, and is 3 ft. in length; but of course any other length could be adopted that might be thought more convenient. At the top of the first division of the levelling staff a band is attached, about 2 in. wide, which is graduated upwards, and forms an accurate continuation of the scale on the lower division of the staff. The last-mentioned band passes over a brass roller attached to the top or innermost division of the staff, and is from thence carried down and under a brass drum (on which it is wound) fixed just below the roller to the top of the same staff, the band being kept in tension by means of a box spring attached on one side of the axis of the cylinder.



SIDE VIEW.



FRONT VIEW.

It will be seen from the above arrangement that when the second division of the staff is drawn out, the band unwinds and gives a continuous reading up to 5 ft. 8 in., or for any intermediate distance that the height of the roof will allow, the band being kept in tension at the required elevation, and lying flat against the face of the second division of the staff. In the same way, when the third division is drawn out, a continuous reading may be obtained up to 9 ft., or for any intermediate distance, as before.

CHAPTER XV.

THE THEODOLITE.

In mining operations all angles are measured from the magnetic meridian, and the attachment of a telescope and outside vernier to a circumferentor is often inserted to render the instrument capable of performing the same operations in surveying as a theodolite. The superiority of a theodolite will be admitted when it is remembered that the accuracy of observation in an ordinary dial entirely depends upon the fine performance of the needle, while the theodolite records angles between any two or more given directions independent of the magnetic meridian. Great care must be exercised in taking the bearings with a circumferentor. As already stated, any iron plates or rails near the instrument would exert an influence to disturb the needle. The ordinary magnetic needle when mounted so as to be free to move in any direction would come to rest in a position which would be not only so many degrees to the west or east of the astronomical or true north, but its north end would also dip. The mean magnetic dip at Greenwich is at present equal to an angle of about 67°. The needle in a compass-box is, however, so pivoted as to be constrained to move in a horizontal plane only, and by means of a sliding counterpoise, which is attached so as to be adjustable upon the needle itself, the tendency to dip is obviated. The compass-box attached to a circumferentor being usually of a large diameter, it is necessary to ascertain that the long needle which it contains is properly balanced to obviate the effects of dip.

The angles recorded by a compass refer to the magnetic meridian, while the angles recorded by a theodolite may have reference to any zero line to which the index is set when at work. The magnetic bearing of an object is taken in the theodolite by simply reading the angle pointed out by the compass needle when the object is bisected.

THE THEODOLITE

THE VERNIER

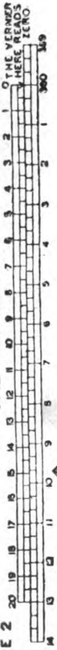
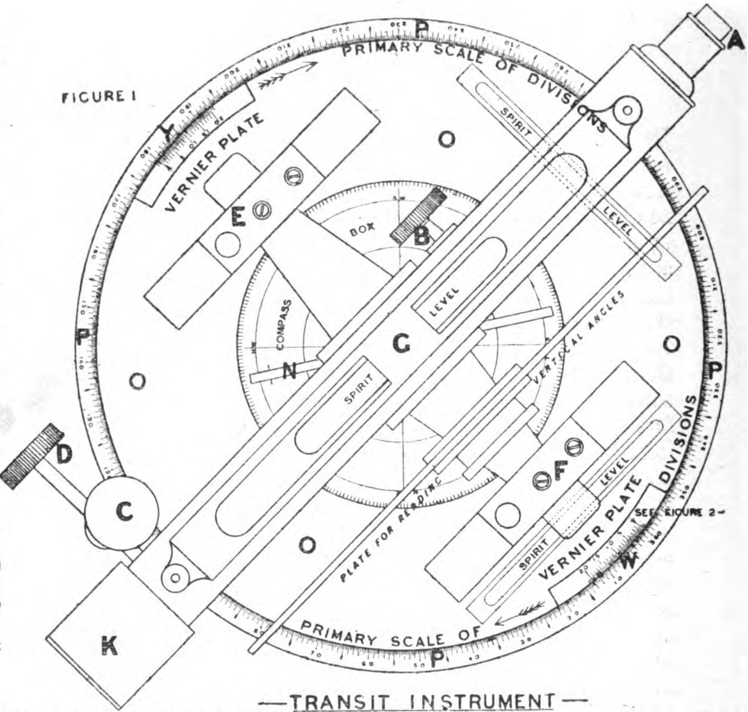


FIGURE 2

FIGURE I



—TRANSIT INSTRUMENT—

NOTE—ONE DIVISION ON THE PRIMARY SCALE = $\frac{1}{3}$ DEGREE = 20 MINUTES

ONE DIVISION ON THE VERNIER SCALE = $\frac{39}{40}$ OF ONE DIVISION ON THE PRIMARY SCALE.

NOTE—THE DIFFERENCE BETWEEN ONE DIVISION ON THE PRIMARY SCALE AND ONE DIVISION ON THE VERNIER SCALE IS EQUAL TO HALF A MINUTE

$$\frac{1}{39}-\frac{1}{40}=\frac{1}{39\times40}=\frac{1}{1560}\times\frac{13'\times60}{1}=\frac{1}{2}\text{ MINUTE}$$

Referring to fig. 1 above, which illustrates the plan of a transit theodolite, it will be seen that the eye-piece of the telescope is marked A and the object-glass end K, that the telescope is balanced upon an axis which is supported upon verticals marked E and F, which are attached to a top-plate carrying one or more verniers. Thus, the telescope can be reversed in its standards both at the eye and object-glass ends. In fig. 1 two verniers are shown in positions marked W and Y. These are placed diametrically opposite to one another, and the plate marked O, which carries them, slides over another plate marked P, the outer edge of which is bevelled to the figure of the frustrum of a cone, and contains the primary scale of divisions graduated to read continuously round it, with the sun from right to left when facing the instrument and up to 360°. The faces of the verniers are continuations of the same conical surfaces, and are graduated to read to the required sub-divisions. The vernier shown in fig. 1 reads to 30 seconds, and the best security is to purchase an instrument direct from a maker who possesses a good dividing engine. An arm projecting from the vernier plate marked O carries the screw C for clamping the verniers, after the telescope has been ranged, when viewing an object in a manner about to be described; and the tangent screw D is for moving the vernier plate a small amount, in order to accurately set it to any required angle, or to set the line of sight in the telescope truly in the correct direction. The importance of attention to this detail is seen in the fact that a minute of arc causes an error of over 18 inches in a distance of one mile. The object viewed is focussed in the telescope by means of the milled head marked B, which acts upon a rack and pinion inside the telescope, and moves an inner tube containing the object-glass backwards and forwards in a perfectly straight line within the outer tube, which holds the eye-piece. For convenience of reading the verniers they are placed in any suitable position upon the arc, but not under the line of the telescope. In fig. 1 they are shown in a line at right angles to the telescope. The facility of vernier readings is determined by the closeness of the vernier and primary scale plates. The lower plate, marked P, is made to revolve round the vertical axis of the instrument, and can be clamped in any required position, as will be explained in this chapter. The diameter of the circle formed by the graduations of the primary scale of divisions gives the nominal size of the instrument. This diameter generally varies from 3 in. to 8 in., although for special purposes larger sizes are made. How the circle came originally to be divided into 360 divisions is a matter of speculation. It probably is due to the fact that the radius of every circle is equal to a chord of 60 degrees, or two thirds of a right angle, and divided the circle into six parts.

The diaphragm plate is sustained within the outer tube by four capstan-headed screws, by means of which the line of collimation is adjusted in a manner about to be described. When required to be adjusted, take care to loosen the capstan-headed screw on one side before tightening the other, and be sure they come to a fair bearing with each screw. Nothing more than this is necessary. It is a fallacy to suppose that the tighter these screws are forced the firmer and more lasting will be the adjustment. On the contrary, something must be strained, and every change of temperature is then more liable to alter the adjustment. Hence the opticians provide only a short lever pin in the box to be used for this purpose. Upon this plate, as shown in fig. 7 (pages 116-118), are fixed the "cross-hairs," intersecting one another within a circular hole in the centre of the plate, and consisting of spider's lines, one horizontal, two vertical, and two deviating slightly to opposite sides of a central vertical line, crossing one another in symmetrically-disposed acute vertical angles, so arranged as to guide the eye in both a vertical and horizontal direction, as well as to define a central point. The cross-hairs are first focussed when setting up the instrument, because the subsequent alteration of the object-glass does not affect them. The dark glass cap supplied in the box with the instrument fits on to the short eye-piece, and is intended for use as a sun glass.

One of the first adjustments requisite in the use of the telescope is known as the adjustment for parallax. The eye-piece marked A is moved in and out of its socket until the cross-hairs are not simply observed but seen distinctly. This adjustment, which will obviate any apparent change in the position of an object caused by a

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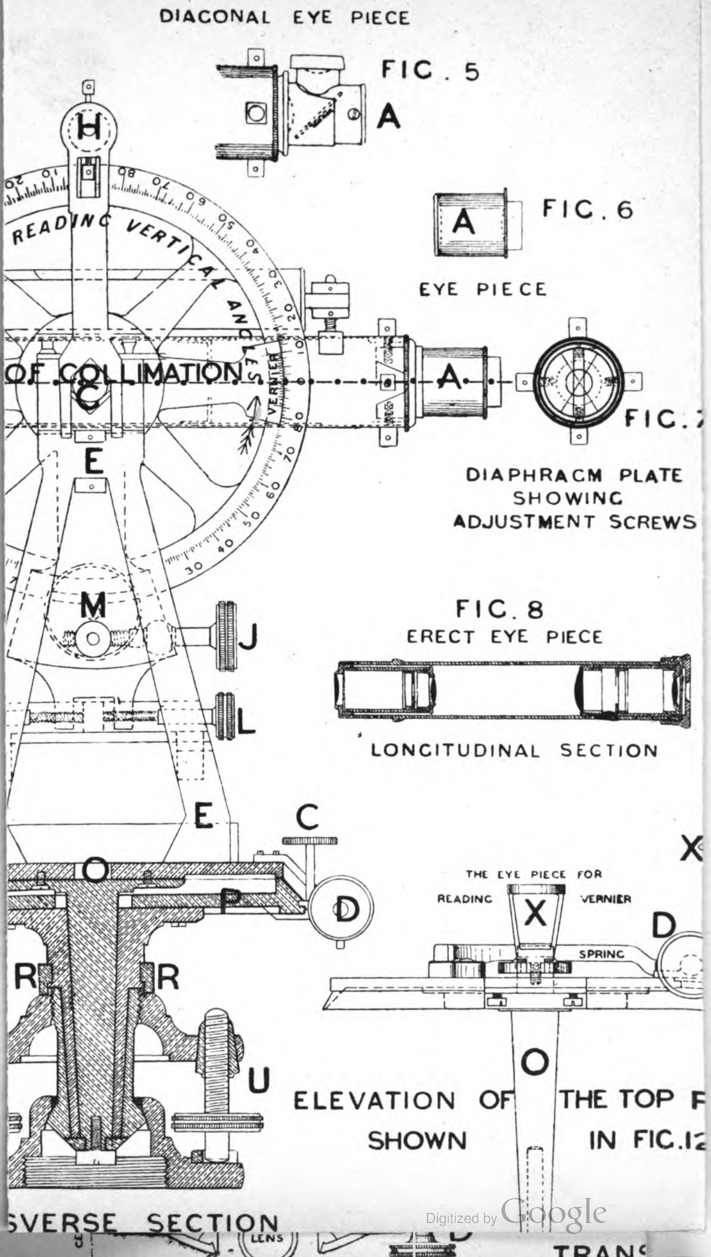
THE THEODOLITE

TRANSIT INSTRUMENT



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slight change of position in the observer, may be best affected by directing the telescope towards a white ground, or towards the sky, so as to project the cross-hairs upon a clear disc. It must be verified each time that the instrument is set up for use. To intersect a given object, the eye-piece being set to observe the cross wires distinctly, acts as a magnifier. As the socket which holds the eye-piece is screwed on to the near end of the telescope, it is advisable, in order to avoid unscrewing the socket when varying the distance of the eye-piece, always to revolve it when necessary in the direction of the hands of a watch.

In a transit instrument, when this socket is unscrewed, a diagonal eye-piece, consisting of two tubes with a rectangular elbow fitted in a separate socket, as shown in fig. 5, can be attached for observing great altitudes. A ray of light entering by the axis of one tube is reflected by the mirror centrally through the other tube. It will be observed that the image of the object viewed is inverted within the telescope when the short eye-piece is used, but by the substitution in the socket of an additional tube, shown in fig. 8, an erect vision may be obtained. The extra glasses and additional length of tube, however, cause a loss of light, and hence the long eye-piece is seldom used, as sharp, distinct vision is of primary importance. After adjusting for parallax, the side milled head, marked B in fig. 1, is turned so as to cause the object-glass to travel out until all fluttering or undefined appearance ceases, and the foci of the object-glass and of the eye-piece coincide. This is known by the distinctness of the image in the telescope. The clear vision is aided by the introduction of stop-pieces, shown in fig. 9, and fixed within the inner tube, as indicated by dotted lines in fig. 3. These serve to avoid reflected light, and to aid sharp definition. It should be noted that the adjustment for parallax must precede that of collimation.

The extent to which the inner tube can be moved in and out is indicated by the dotted lines in the diagram, and the slide shade marked K is intended for use when the sun is shining powerfully upon the object-glass, or when rain is falling. The nearer the point viewed, the further out must the inner tube be propelled so as to focus the object.

To protect the transverse bubble Q from contact with the slide shade cover when the telescope is traversed with the shade or the object-glass tube out, as shown dotted in fig. 3, a small wire hook guard is fixed to the stage, as shown upon the left-hand side of the spirit level Q in fig. 3.

The name theodolite is derived from the Greek θεάομαι (theaomai), or θεῶμαι (theomai), I see, or θέω (theo), I run, and δολικός (dolikos), long, and the instrument is specially adapted for long vision; but it is the maker's business to see that the telescopic action of the tubes is sufficiently perfect, in order that the line of collimation when adjusted for a long distance may be correct for a short one. The two small spirit-levels over the top horizontal plate are fixed at right angles to one another. They are adjusted in position by the makers by means of the capstan-headed screws attached to them. The long bubble attached to the telescope of a theodolite is seldom used in ordinary surveying.

The tube containing the liquid is nearly filled with spirit, and is hermetically sealed. A bubble of air occupies the small portion of the tube not occupied by the spirit, and great pains are taken by the manufacturers to make these bubbles sensitive. The inside or soffit of the level-tube is carefully ground with emery powder and water, upon a brass rod which is bent to a slight curve longitudinally upon the inner upper surface, so as to insure the steadier action of the bubble when the tube is filled to the required amount. Spirit is found to be a more manageable medium in adjusting the bubbles than water. It is also less liable to freeze in cold weather. The grinding of the tubes may be so accurately executed as to enable the steady deviation of the bubble from the centre of its run to register small angular deviations from the horizontal. It will be found that the length of the bubble is affected by temperature, and hence the glass tubes are generally graduated upon their upper surfaces by transverse lines marked upon it with a diamond, in order to guide the eye in setting the bubbles level.

The material employed for theodolites and similar instruments is usually brass, though of late years gun-metal has been used by some manufacturers. The upright frames marked E and F in fig. 3 and the stage to which they are fixed, are made of cast brass composed of good copper and good zinc, known as "free brass," that is, brass quite free from iron. The presence of a minute portion of iron would seriously influence the action of the compass. The upper and lower parallel plates and the staff head to which they are attached are also made of cast brass. The elevating screws U U and Z Z are made of gun-metal. The screws marked M, J, L, C, and D are made of drawn or wrought brass, but the collar marked R and the clamping connexions are made of cast brass. The spirit-level tubes Q and T are made of wrought brass. In brass instruments, the inner vertical axis, to which the stage marked O is attached, is made of bell or of gun-metal, and the surrounding piece to which the limb marked P is attached is made of cast brass. The horizontal axis of the telescope and the telescope collars are also of bell-metal, which is used partly upon account of its greater hardness and partly because bell-metal works upon brass with less friction than brass upon brass or bell-metal upon bell-metal. The limb marked P and the vertical arc are made of cast brass. The finished pieces are treated in the following manner in order to give them a dark exterior appearance upon account of the glare produced by a smooth brass surface. The clean brass pieces are immersed in a liquid containing nitro-hydrochloric acid, consisting of platinum dissolved in a mixture of muriatic and nitric acid. The chlorine liberated by the nitric acid from the hydrochloric acid being *in statu nascenti* readily attacks the metal. The pieces are afterwards brushed with graphite and lacquered. Electrum, as it is called, is an alloy composed of pure nickel and copper, and possesses the advantage over plain brass, that its surface does not tarnish by the action of the perspiration from the hand. While its colour nearly equals the whiteness of standard silver, it is stiffer and of less specific gravity. Hence it is used for drawing instruments and for such portions of field instruments as need a bright surface upon which to distinguish the graduations.

The telescope, as shown in figs. 3 and 4, is mounted to turn both upon a vertical and a horizontal axis, so that when the theodolite is in perfect adjustment it is not necessary for the objects which are ranged by the instrument to be either in the same vertical or in the same horizontal plane, as will be seen upon reference to figures 3 and 4. To the underneath of the bottom horizontal plate or limb of the instrument, marked P, is attached a hollow body-piece, having a solid conical axis working within it, upon which the top horizontal plate or stage, marked O, is fixed. Both of these work concentrically within a jacket, which forms the connecting-piece to the parallel plates, as shown in fig. 3. The upper parallel plate is attached by a screwed end to this jacket, and the lower parallel plate is connected by a half-ball-and-socket joint, the bearing being maintained by three or four elevating screws, which are marked U and Z, and which keep the upper and lower plates apart. All the wearing surfaces are turned and bored, so as to fit accurately, and the concentric pieces are secured by a washer and set screw, which is shown beneath the half-ball-and-socket joint. The vertical axis upon which the vernier plate turns, and the vertical axis upon which the entire instrument revolves, should be the same, and the bubbles to the levels when adjusted to one centre should reverse upon either one at will. The parallel plates are held in a relative position to one another, in figs. 3 and 4, by means of a stop-block, within which one of the screws is placed, and the fine thread requisite for minutely adjusting the plates is provided with elongated nuts, which are bushed into the upper plate. (See pages 116-118.)

The screws marked U and Z have large milled heads provided for turning them. It must be remembered that in a four-screw combination of parallel plates the centre lines of opposite screws cross one another at right angles in plan. In adjusting the parallel plates, as shown in figs. 3 and 4 (pages 116-118) and figs. 13 and 14 (pages 125-127) two opposite screws are held between the thumb and first finger of each hand, and are turned simultaneously in contrary ways one to the other, so that by moving the corresponding screws U U, or Z Z, both round towards the centre of the parallel plates, or both out from the centre of the plates, the upper plate is by this action lowered upon one side and raised upon the other. These are sometimes called the azimuth screws, because they serve to adjust the instrument in azimuth, that is to say, horizontally, to the right and left, and these screws should always work easily. If one of them appears hard to turn, it indicates that this screw is being unduly strained, and that it must not be further tightened until the opposite screw has been slightly loosened or slackened. It is never desirable to oil or grease the screws in the field, as it tends to introduce grit and dust into the threads. When required for cleaning purposes, the oil or grease must be used very sparingly, and carefully worked off, before again setting up the instrument out of doors.

The delicacy obtained in the process of levelling, by the fineness of the pitch given to the threads of the elevating screws, is further increased in the three-screw arrangement of parallel plates, shown in figs. 15-18 (pages 125-127), by the comparative greater distance from the vertical axis of the instrument at which these screws are worked. The parallel plates here form a tribach, having three radiating arms or branches forming a part of the body piece, near the outer extremities of which the connecting adjustment screws are placed. The upper plate is about $\frac{1}{8}$ in. thick, with a vertical flange carried round its edge, and at the projecting extremities of each arm, solid bosses of a suitable depth are cast, which are tapped to receive the threads of the elevating screws. In fig. 16 each screw terminates in a semicircular ball, which rests in a socket upon the lower parallel plate, and is secured by a locking plate, which is clamped by tightening one or more of the three set screws. Thus a uniform motion is obtained without indenting the lower parallel plate on which the screws rest. In a four-screw combination of parallel plates they are, on this account, often made to bear upon small thin pieces of leather, glued to the top of the lower plate, under each screw. The value of leather washers under the parallel plate screws is open to argument. They are supposed to absorb shocks but are found to be affected by weather and by the pressure of the screw ends. In order to avoid bending the central connecting portion when adjusting the parallel plates by means of their elevating screws, a slot shown in the section (fig. 14), and marked "opening" in the plan (fig. 13), has sometimes been introduced into the upper plate. With a four-screw arrangement of parallel plates care must be taken that all four screws bear upon the lower plate or the instrument cannot be expected to work steadily. If one screw be moved more than the other, one of them is apt to be raised off its bearing plate, and the upper portion carrying the limb and stage will then rest upon the three remaining screws and be liable to rock. Hence both hands are necessary to be applied in adjusting the opposite screws, but with a three-screw arrangement of parallel plates the screws may be adjusted with one hand. The disposition to rock is also obviated, as an instrument requires at least three points to rest upon, and hence the well-known saying, "as right as a trivet." In this three-legged support, the elevating screws form the only attachment when locked between the tripod head and the instrument. In the arrangement of a three-screw combination of parallel plates shown in figs. 17 and 18 (pages 125-127), it will be observed that any tendency to vibrate in working the instrument is kept below the locking plate, and that the locking plate, a plan of which is shown in fig. 19, assists to maintain the rigidity of the parallel plate connexion. Fig. 20 illustrates the detail attachment of one of the vertical screws, and fig. 21 shows the washer plate for securing the locking plate in position by means of the clamp screw. To counteract any wearing away that may occur after some time in the screw portion of the projecting arms to the upper plate, a vertical slit is generally made in the end of each arm, and a side capstan-headed screw provided to each for clamping the joint. A new instrument may perhaps work stiffly at first, but a few days' use will soon cause its parts to be easily acted upon. Three screws can not jamb, as is so often the case when a beginner works with a four-screw instrument. The locking plate in a three-screw instrument also prevents either screw rising off the lower plate.

In order to set up the theodolite, the lower parallel plate is screwed to a tripod head or centering stand, and the parallel plate screws are adjusted at the outset, so as to bring the upper and lower plates parallel to one another. The instrument is then so placed with its vertical axis

THE THEODOLITE

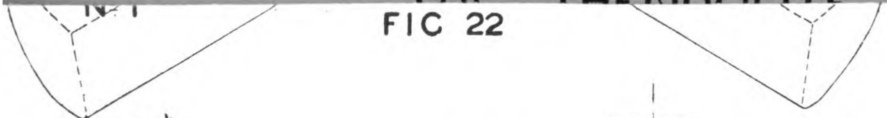


FIG 22

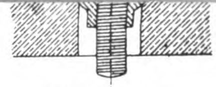
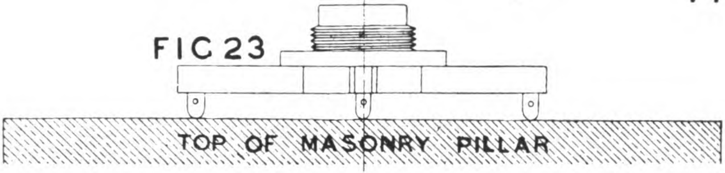


FIG 20

FIG 23



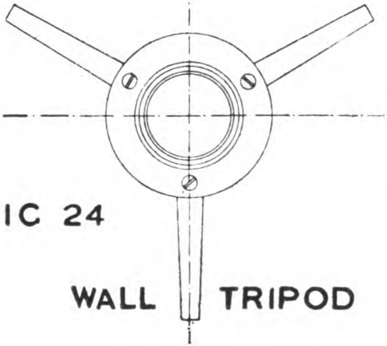


FIG 24

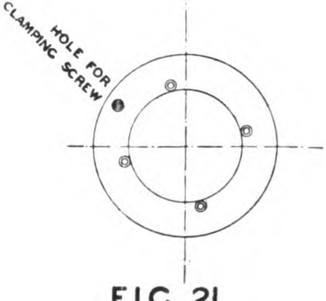


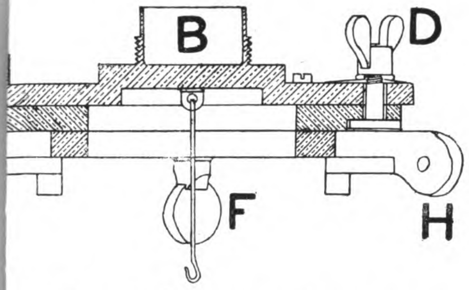
FIG 21

[Field Work and Instruments, pp. 125, 126, 127.

plumb over a station point, that only a very slight range of obliquity to the parallel plates may be requisite when finally adjusting the bubbles to the centre of their run. Skill in working these screws can only be acquired by practice. They should be hand-tight, but never forced, otherwise their threads will soon be destroyed, and the perfect action of the instrument impaired. On the other hand, slack screws are as prejudicial to the working of the instrument as tight screws are dangerous to the mechanism. Fig. 22 shows a plan of a theodolite mounted upon a tripod stand. In the case of a four-screw combination of parallel plates, the levels marked Q and T are first turned parallel to the diagonal direction of two opposite parallel plate screws. In the case of a three-screw arrangement of parallel plates, one bubble tube is set parallel to the direction of two adjacent parallel plate screws, and then the other bubble tube will be parallel to a line at right angles to the line which joins these two screws, and which passes through the third screw. This will be evident upon comparing the centre lines which cross one another at right angles in figs. 13, 15, and 17. Having done this, the next thing is to set these bubbles approximately in the centre of their run by extending the legs of the tripod marked as No. 1, No. 2, and No. 3 in fig. 22, taking care at the same time so to finally place the instrument that the plumb-bob which is suspended from a hook or chain under the head of the instrument hangs freely exactly over the centre of the fixed station. To effect this, it will be found that the best plan in practice is to consider one leg of the tripod fixed, and, while keeping the eye both on the station point and the bubbles, to adjust with the other two legs, taking hold of one with the left hand and the other with the right hand. Supposing that the leg marked No. 3 has been selected as the fixed one, the bubble marked Q is adjusted to the centre of its run by moving the leg marked No. 1 in the direction indicated by the arrows and the bubble marked T by the leg marked No. 2. In thus adjusting the legs, care must be taken to lift each leg only just clear of the ground, but no more, otherwise the level of the other bubble will be considerably affected thereby. This process must be repeated, first as regards one bubble, by means of its corresponding leg, and then with the other bubble by means of the other leg, until both bubbles appear level, care being taken not to kick or even to touch either leg of the tripod when set, while observations are being taken; and previously observing that the plumb-bob remains over the station point, the surveyor should press the legs gently but firmly in the ground, sufficiently to ensure the stability of the instrument, then finally adjust the levels Q and T by means of the parallel plate screws. This is effected by a wrist motion, the movement of the right hand in adjusting these levels either in or out, when turning the milled head elevating screws giving the direction in which the bubble travels. The importance of paying careful attention to accuracy in setting up the theodolite is evident when it is remembered that an arc of a single minute subtends a distance of from 4½ in. to 4⅝ in. in a radius of 20 chains or one quarter of a mile.

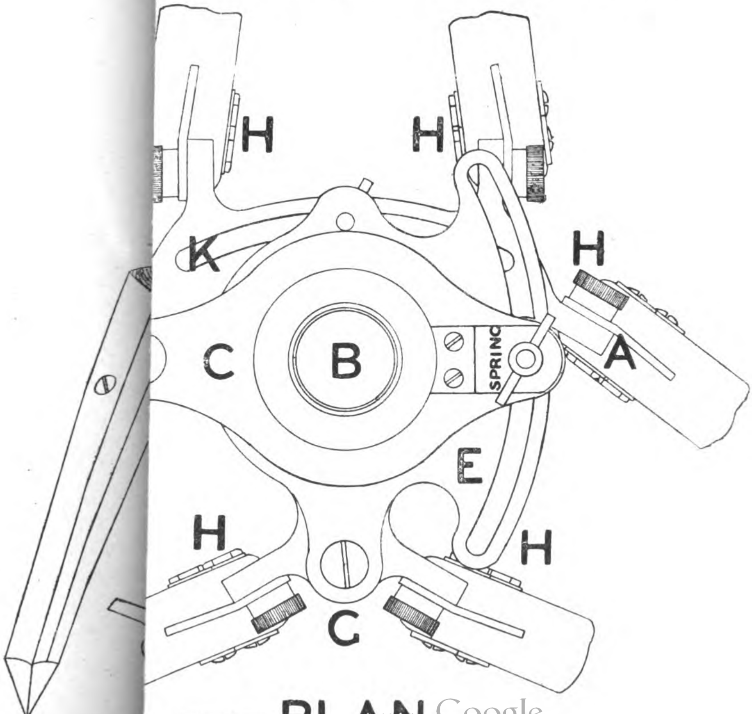
The stand of the great theodolite used in the Ordnance Survey was a strong, circular, four-legged mahogany table, firmly braced, upon which the instrument rested on three feet. Figs. 23, 24 (pages 125-127) show the usual form of wall-plate adopted for setting up the instrument over a permanent station, such as a brick or stone pier. When the coping stone is being fixed, it should be bedded true and the upper surface squared, so as to save trouble in subsequently working with the instrument when setting it up in this position. With the use of an ordinary tripod head much time is frequently employed in levelling the instrument over a fixed peg or station point, during which time the assistants are generally kept waiting. The plumb-bob is usually hung from the centre of the head of the tripod by means of a piece of stretched thin cord. A short piece of chain attached under the centre of the tripod head to suspend the plumb-bob from, is preferable to a long-shanked hook rigidly fixed, as it adjusts itself better to a vertical line when the legs stand upon uneven ground. If, during the process of setting up the theodolite, the bubbles marked Q and T appear level or nearly level, but the plumb-bob does not hang exactly over the point required, it indicates that the third or fixed leg needs shifting a trifle and the above operation must then be

NTERING STAND



SECTION A-A —

HTON & SIMMS' PATTERN —



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ASTOR, LENOX AND
TILDEN FOUNDATIONS.

repeated. More is to be gained by rapid setting-up than by quick reading. Too much rapidity of reading is likely to lead to inaccurate records, indeed to overcome any mechanical inaccuracies in the instrument, it is prudent in the case of long lines to repeat the angles. Thus, if an angle reads 60° 15′ the first time, the next record should read for the same angle 120° 30′, and the third record 180° 45′.

With the view of facilitating the setting up of the theodolite over a given station point, and to maintain the line of the plumb-bob in the same line as the vertical axis of the instrument, various kinds of centering-stands have been manufactured. Messrs. Troughton & Simms attach to all their three-screw combinations of parallel plates connected with theodolites, a centering locking-plate, in which provision is made to allow of a motion of 1-in. in any direction for the adjustment of the plumb-bob over the station point, the centering-plate being tightened after setting over the station by a screwed washer-plate. This plate is somewhat similar in shape to the washer-plate shown in fig. 21, but has a raised thumb-piece at its outer edge, for screwing up or down the collar which holds the vertical axis of the instrument. By this means the locking-plate and the instrument are both clamped to the tripod-stand, or released without the addition of extra clamp screws. Messrs. Troughton & Simms also make a framed stand, shown in fig, 25, with an arrangement of plates shown in section in fig. 26, and in plan in fig. 27 (pages 130-132). With the usual form of tripod, the range over which the head may be shifted in adjusting the plumb-bob is necessarily very limited, but with a framed stand a larger opening in the base of the system can be introduced for this purpose. The theodolite is fixed at B by the ordinary screw attachment to the bossed plate marked C. The middle plate marked E has two pivot connexions, the centre lines of which meet at right angles to one another at the centre of the plate. To one of these pivot connexions, the top plate is attached by a screw-bolt, which is secured by a capstan-headed nut, shown at the left-hand side of the section. To the other pivot connexion the lower plate is attached in a similar way at a point near G in plan. The lower plate marked K is connected to the framed stand

THE HOFFMAN

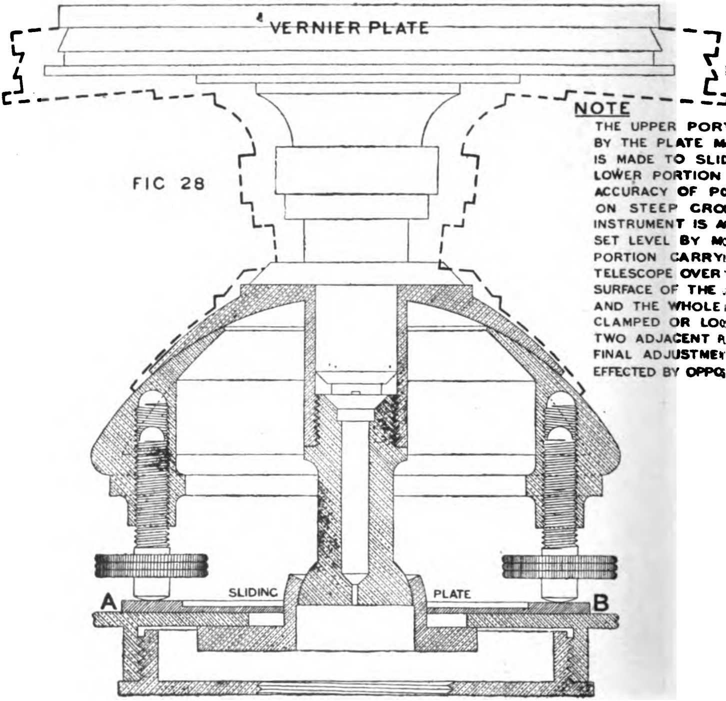

FIG 28

NOTE

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TRANSVERSE SECTION

[*Field Work and Instruments, pp.* 134, 135.

IAN TRIPOD HEAD

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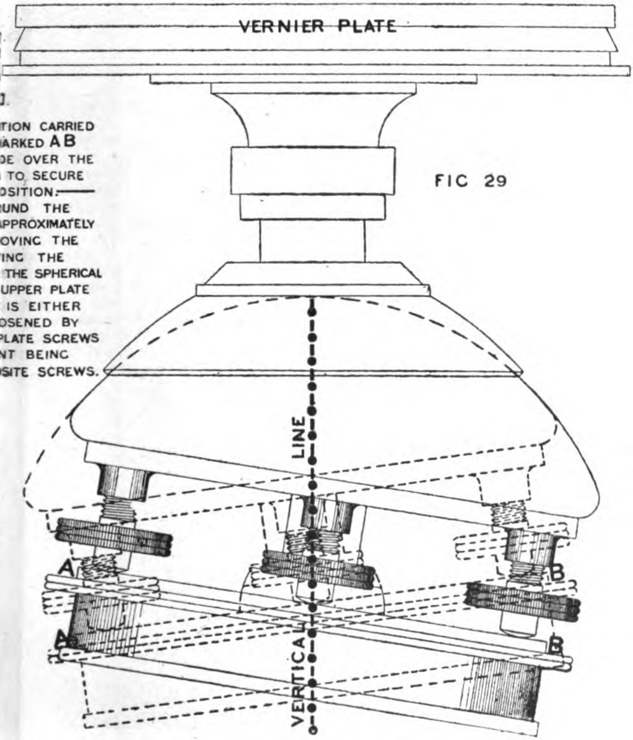


FIC 29

at the points marked H. The radial movement of the top plate over the middle plate and of the middle plate over the lower plate is regulated by a quadrant slot in the middle and lower plates, and the circular hole of 3 in. diameter in the lower plate allows ample play for the adjustment of the plumb-bob line to the vertical axis of the instrument. The top plate is clamped to the middle plate in any required position by the thumb-screw marked D, and the middle plate is clamped to the lower plate by the thumb-screw marked F. Thus the theodolite can be levelled, first when approximately set up over a station point, and finally moved accurately over this point by adjusting the centering plates.

In the progress of the Ordnance Survey in order to obviate the tremors usually transmitted to the instrument under ordinary circumstances, the theodolite was at all main observing stations isolated. This was generally effected by the introduction of a double set of framework, one inside the other, so arranged that the two scaffoldings over the station point were independent of one another, the inner one carrying the instrument while the observer stood upon the outer one.

The tripod head shown in figs. 28, 29 (pages 134, 135), is an American invention by Mr. Daniel Hoffman, combining the action of a ball-and-socket joint with the rigidity of the ordinary parallel plates. The upper plate is made in the shape of a circular curve, concentric with the half-ball and socket-joint, and the hook or chain from which the plumb-bob is suspended is fixed at the centre of these curves. The elevating screws to the upper plate rest upon a sliding plate, and their centre lines will at all times be parallel to the vertical axis of the instrument in any position that the horizontal limb and stage over which the telescope is mounted may assume with regard to the tripod head. The amount of range available for thus setting the head of the stand level upon steep ground is indicated in fig. 29. The shifting head of the tripod and its sliding plate are clamped by tightening any two adjacent screws, final adjustment of the levels Q and T being effected by opposite screws in the usual manner. The plumb-bob usually supplied in a theodolite box is scarcely heavy enough for ordinary work. One such as that shown in fig. 25 (pages 130-132), or like that indicated in figs. 31, 32 (pages 140-143) is more generally adopted.

The instrument moves under all conditions upon a centre common to both ball-joints, this centre being the point to which the hook or chain is attached for suspending the line of the plummet. It is therefore impossible for the plumb-bob to hang otherwise than perpendicularly to the horizontal axis of the instrument, and it will be observed that the radius of the curve to the inside of the upper plate is considerably larger than that of the half ball connecting the same with the sliding plate, and to which the point of suspension of the plumb line is also attached. When the levelling screws are used to level the horizontal bubbles of the vernier plate in a Hoffman Head, the entire instrument turns about the lower small half ball, while the larger upper one remains tightly clamped, as if it had no existence. It is only when the levelling screws are slackened, that the instrument can be moved over the upper large ball surface.

When a tripod head with its levelling screws can be detached and packed away in the box with the instrument proper, the carriage proves more convenient than when it is fixed to the legs. Fig. 30 shows the ordinary form of tripod to which the instrument is attached when required to be set up for use in the field. In travelling, the tripod should have a cap to its head, and a ring to confine the legs. More than one ring is not necessary. The cap-piece is first unscrewed and the legs spread open as shown in figs. 31, 32 (pages 141-143). When these wooden legs are closed, as shown in fig. 30, and the adjacent edges of the three sections are rounded off in the positions marked V for about 1 ft. in length, the legs can be more readily separated by applying the fingers to open them and to set them up in any desired position, just as a pair of compasses or dividers in an ordinary box of instruments may be easily opened when the adjacent edges are bevelled in this manner.

It will be observed in figs. 30 and 31 that the stock or staff-head to which the cap is screwed is connected to one central lug upon the top of each leg, whereas in fig. 32 there are two lugs to the top of each leg and one central lug upon the stock or staff-head. In fig. 31 the connexion to each leg is made by a large surface bearing-pin, which is tapped at the end to receive a slot-headed tightening-screw. In fig. 32 the joint is made by a bolt and nut, and the cap-piece, shown in fig. 33, is constructed to act as a box-spanner for tightening the nuts on each leg. The arrangement in fig. 32 is preferable, inasmuch as the result of drawing the cheeks between which the leg joints work in fig. 31 nearer together, as wear goes on, only causes their lower ends to approach and leaves the wear of their upper surfaces unprovided. These considerations are obviated when a stand as shown in fig. 25 is adopted. When the theodolite is mounted on the tripod-stand, it is usually carried by the surveyor over his shoulder from station to station in the field. In rough open country it is best to shoulder the legs with the instrument at the back, because the feet of the tripod would then first meet the ground and save the instrument from damage in the event of the bearer tripping up, but in the well-paved road of a town, it is better to shoulder the tripod with the instrument in front of the surveyor, because should he turn round thoughtlessly or rapidly without his eyes on the instrument, it might knock against an obstruction and sustain injury. Before carrying the theodolite from station to station, the parallel plate screws should be turned hand tight, and the needle in the compass-box thrown off its centre, otherwise the agate bearing upon which the needle is balanced will soon become worn, and the sensibility of the magnetic action impaired thereby; but all clamp screws should be slackened, as the parts will then adjust themselves better to one another in the event of the instrument sustaining a jar or shaking. Before packing the theodolite into its box, the screws marked C, R, and M, for the same reason, should be unclamped. The loose collar marked R terminates in two lugs, that through which a screw passes, being tightened, clutches round the body piece and holds it tightly. A bracket also attached to this collar is connected with a sphere (fig. 4, pages 116-118) moving on a pivot from the bracket, and pierced to receive a screw working tangentially to the vertical axis.

There are various types of theodolites, all excellent instruments, but each having some distinguishing feature identified with the manufacture. However much they may differ in detail they all possess three principal movements independent of the movement of the parallel plates.

(1.) The relative movement of the vertical arc or circle is clamped by a screw marked M, the tangent screw marked J being intended for final adjustment only when the clamp screw M is tightened. Figs. 34 and 35 show side elevations of a plain or modern Y theodolite, fig. 36 being an end view, and fig. 38 a plan. In this instrument the telescope is attached *above* the horizontal axis and is supported in two forked rests called Y's, but which are in this case U-shaped, and which form the ends of a bar fixed at right angles to the horizontal axis. The telescope is generally soldered to collars, which rest movably and reversibly in the Y supports, and is clasped firmly in its Y's by two semicircular clips, which are hinged to each Y at one side, as shown at G in fig. 36, and fastened with a pin at the other side, as shown in fig. 34. As the pin sometimes may work loose, a safer attachment is shown in fig. 37, where a spring connexion is secured by a small milled-head screw. The use of circular instead of tangential bearings or U pieces in place of Y bearings, reduces the tendency to derangement by shaking, when carrying the instrument about, to the smallest possible extent. When required, the telescope can be lifted out of its Y's or U supports and reversed end for end in its supports. Vertical angles of elevation or depression are taken by revolving the telescope, as indicated by the dotted lines in fig. 35 and reading the semicircular arc, upon one side of which are marked degrees, as indicated in fig. 34, and upon the other side the difference between the hypothenuse and base, as shown in fig. 35 (pages 141-143). The vertical range in this instrument is limited by the position of the connecting piece marked L, to which the vernier is attached. In a transit instrument the telescope revolves *upon* its horizontal axis, the Y supports, which carry the trunnions, being made high enough to admit of the telescope being turned completely round in a vertical plane when the instrument is set up level. (See fig. 3, pages 116-118.)

In a transit instrument, the horizontal axis forms the centre line of the trunnions attached to the telescope, as shown in fig. 4. The trunnions are shouldered down at their outer ends, and are connected at their inner ends to the telescope by means of a collar-piece fixed round the outer tube at or near its centre. The axis is supported and movable upon V-shaped sockets or angular bearings, technically termed Y's, in which it is held by movable clips, consisting of thin flat brass plates, attached to one branch of the V by a fixed screw, and secured to the other branch by a small milled-head screw, as shown in figs. 39, 40 (pages 148-150).

The vertical circle, as shown in fig. 3, is divided into four quadrants, the degrees in each of which are numbered from zero in a horizontal line to 90° in a vertical line. Two indices with verniers at opposite ends of a fixed horizontal bar record any vertical angle required, and are attached to the axis of the arc for reading the angle more clearly. The graduations are made upon an inlaid ring of silver or palladium. A transit instrument is of all others the best adapted for ranging straight lines over an intermediate station on a base line, as the necessity of turning the telescope (shown in figs. 34 and 35) round horizontally or of reversing it end for end is obviated by revolving it in its supports. In measuring horizontal angles the telescope is merely traversed round the horizontal axis to suit the different altitudes of the distant points observed, and the vertical clamping arrangements M and J are seldom used.

(2.) The absolute horizontal movement of the body of the instrument round the centering of the top stage. By means of a thumb-screw marked R, a collar which is supported by the upper parallel plate can be tightened and the body piece clamped, the tangent screw marked S, which rests in a vertical pivot bearing connected to the upper parallel plate being intended for slow motion in final adjustment when the clamping collar is so tightened.

(3.) The relative movement of the top horizontal stage, marked O in fig. 3, carrying with it the telescope and verniers, while the bottom horizontal limb containing the primary scale of divisions remains clamped. These two plates work parallel to one another, the stage being clamped to the limb at C and D, as previously described. In figs. 34 and 35, the magnifying eye-piece marked X for

THEODOLITE

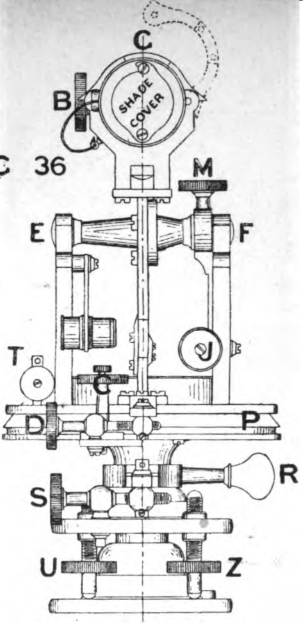


FIG 36

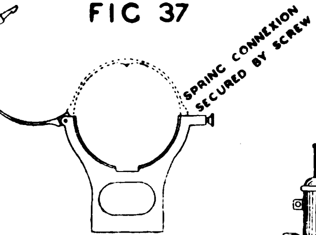


FIG 37

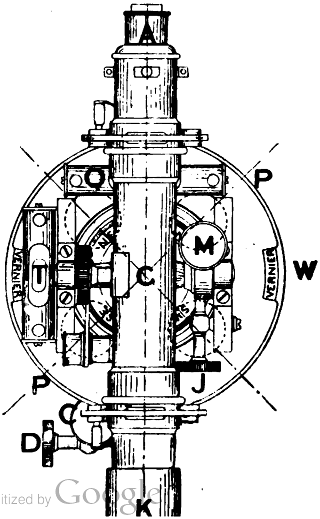


FIG 38

[*Field Work and Instruments*, *pp.* 141, 142, 143.

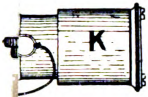
shown in fig. 4. The trunnions are shouldered down at their outer ends, and are connected at their inner ends to the telescope by means of a collar-piece fixed round the outer tube at or near its centre. The axis is supported and movable upon V-shaped sockets or angular bearings, technically termed Y's, in which it is held by movable clips, consisting of thin flat brass plates, attached to one branch of the V by a fixed screw, and secured to the other branch by a small milled-head screw, as shown in figs. 39, 40 (pages 148-150).

The vertical circle, as shown in fig. 3, is divided into four quadrants, the degrees in each of which are numbered from zero in a horizontal line to 90° in a vertical line. Two indices with verniers at opposite ends of a fixed horizontal bar record any vertical angle required, and are attached to the axis of the arc for reading the angle more clearly. The graduations are made upon an inlaid ring of silver or palladium. A transit instrument is of all others the best adapted for ranging straight lines over an intermediate station on a base line, as the necessity of turning the telescope (shown in figs. 34 and 35) round horizontally or of reversing it end for end is obviated by revolving it in its supports. In measuring horizontal angles the telescope is merely traversed round the horizontal axis to suit the different altitudes of the distant points observed, and the vertical clamping arrangements M and J are seldom used.

(2.) The absolute horizontal movement of the body of the instrument round the centering of the top stage. By means of a thumb-screw marked R, a collar which is supported by the upper parallel plate can be tightened and the body piece clamped, the tangent screw marked S, which rests in a vertical pivot bearing connected to the upper parallel plate being intended for slow motion in final adjustment when the clamping collar is so tightened.

(3.) The relative movement of the top horizontal stage, marked O in fig. 3, carrying with it the telescope and verniers, while the bottom horizontal limb containing the primary scale of divisions remains clamped. These two plates work parallel to one another, the stage being clamped to the limb at C and D, as previously described. In figs. 34 and 35, the magnifying eye-piece marked X for

THEODOLITE



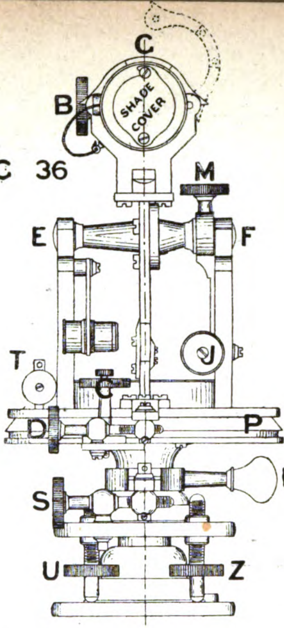


FIG 36

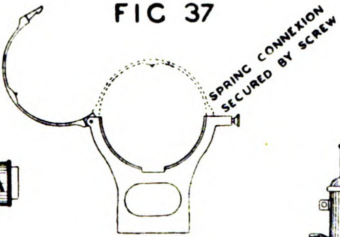
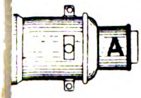


FIG 37



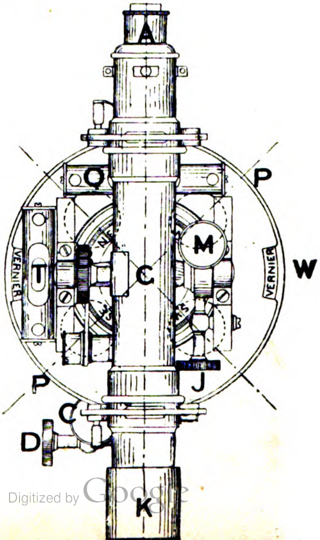


FIG 38

[*Field Work and Instruments, pp.* 141, 142, 143.

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reading the vernier moves round the limb, by working in a re-entering angle or slot under the rim, and is brought over one or the other of the verniers as required. It is desirable that the magnifying glass face should be parallel with the tangent to the graduations that are being read. When the magnifier is arranged to traverse independently of the limb, it is less liable to disturb the instrument in moving it over the vernier. In figs. 3 and 4, each vernier has a magnifying eye-piece to itself. In some instruments, the magnifying eye-pieces are fitted with circular ivory screens to reflect light upon the vernier scales, and also to obviate the glare of the sun upon the silvered surface, which so often renders necessary the shading of the verniers with the hand or book when reading the divisions.

When the centre of the stage within the vertical side frames E and F is occupied by a compass-dial, as shown in figs. 1, 22, and 38, the position of outside clamping arrangements shown in figs. 3 and 34 is generally adopted, but, when this is not the case, the clamp and tangent screws are better arranged as shown in fig. 12 (pages 116-118), where the clamp screw is acted upon by a german-silver spring fixed in the place of the circular compass-box. A long trough compass-box, shown in fig. 10, is attached to the under-side of the limb marked P by four screws through the unshaded grooved portion of the section shown in fig. 11, into which it slides with the needle lifter outside the connexion. The capstan-headed screws shown upon each side at the end of the box are for adjusting the graduated blocks to the respective points of the needle. These blocks are graduated so as to indicate any deviation of the needle, east or west, or of the magnetic meridian, when setting the telescope in this direction.

The glass cover can be removed by opening the hinged flap at the end of the box, which is secured in its place by a milled-headed screw. In figs. 1, 22, and 38, the spirit levels shown in plan upon the stage are of equal length. In fig. 12, one is made longer than the other, and the trough-box containing the long needle is attached to the limb in a line parallel to the longest of these two bubbles, the short bubble being placed parallel to a line joining the zero point of the graduated circle with the opposite division marked

180°, and in a line at right angles to the run of the long bubble. Thus when the vernier plate is clamped at 360° by means of the screws C and D, the line of collimation in the telescope is parallel to the centre line of the compass-box. The stage and limb while clamped are then revolved together, until the needle stands at rest at the zero points upon the graduated blocks in the trough-box. The magnetic meridian being thus determined, the body-piece of the instrument should next be clamped at R, and the stage released by means of the screw, C. Having done this, the telescope is ranged, with the limb clamped, to any given point for observation, and the stage is then reclamped in proper position by the screws, C and D. The rotations of the upper plate or stage are effected by simply touching the telescope, and moving it round, preferably in the direction of the hands of a watch. The angle traversed must be read off the same vernier which was selected to set the instrument to zero. By this arrangement the instrument is capable of serving the same purpose as a miner's dial, in addition to the more extended usefulness of a theodolite. All the micrometer screws should be kept nearly "middled," or half-way through their nuts between each operation.

In the daytime sufficient light is admitted into the telescope to see the cross wires in the diaphragm-plate distinctly; but in setting out tunnels underground, or when the instrument is used at night in astronomical work, the wires would not be clearly seen. Fig. 4 exhibits a small oil lamp, known as the tunnel lamp, which rests upon a side stand attached to one of the upright frames, marked F. When required for use, it is provided with a specially prepared wick. One of the trunnions upon which a telescope adapted for tunnel work revolves, is perforated in the line of the horizontal axis, and fitted with a glass stop-piece so as to provide a transparent bearing in which to admit light from the lamp to the cross wires, the light being transmitted by means of a small diagonal reflector, carried by an arm which is screwed into the outside tube of the telescope, and thus axial illumination is obtained. The reflector and its connexion to the outer rim of the telescope are made as small as possible, so as not to impede the passage of the cone of rays in their conveyance from the object-glass to the cross wires. Thus, when the object observed is also illuminated, clear vision of the point desired along the line of collimation is obtained. (See pages 116-118.)

Another description of theodolite, employed in some parts of India, was designed by Colonel Sir George Everest, and constructed as (1) the single arc Everest, (2) the double arc Everest, but the two patterns differ mainly in one having two vertical arcs, while the other only possesses one (figs. 41-44, pages 148-150) the telescope is permanently fixed to its horizontal axis as in a transit instrument (figs. 39 and 40). The supporting frames are made low for sake of compactness, but the telescope can be reversed end for end by unfastening the clip pieces and lifting the horizontal axis out of its bearings. There are two opposite sectors graduated in degrees from zero to 50°, as shown in fig. 41, instead of a complete vertical circle, as in figs. 39 and 40. These sectors traverse with the telescope, as indicated by the dotted lines in fig. 41, and are placed so as to allow the telescope to traverse within an angle of about 45° above or below a horizontal line, as in a plain or Y theodolite (fig. 35). The long spirit level which, was seen in figs. 3 and 34 to be attached to the telescope in both the plain and the transit types of instruments, is in an Everest instrument attached to the index bar. The index bar carries a vernier at each end, by means of which, sub-divisions of a degree in measuring vertical angles can be recorded. Instead of the two spirit levels marked Q and T in figs. 22 and 38, there is only one spirit level, marked Q in fig. 42, which is fixed parallel to the horizontal axis of the telescope, as shown in fig. 44, the spirit level marked T′ in figs. 41 and 42 being substituted for the spirit level T in figs. 22 and 38.

In place of the top plate or stage which carries the verniers in the plain and transit instruments (figs. 34-40), Colonel Everest's theodolite is supplied with four arms radiating horizontally from the inner vertical axis. Three of these arms are spaced equidistant to one another, and carry an index and vernier scale attached in positions shown in fig. 44, which are read by the aid of an independently traversing magnifier marked X. The four arms are connected to the vertical axis of the telescope so as to turn with it upon the lower plate or limb, and thus to measure horizontal angles upon its graduated edge. The fourth arm carries the clamp and tangent screws, marked C and D for fixing the telescope, in any required position. A trough compass-box similar to that shown in fig. 10 is fixed above the telescope in the position marked N in fig. 43. Instruments which have the telescope mounted upon very low supports possess the advantage of steadiness. This instrument is mounted upon a three-screw combination of parallel plates, the feet of the elevating screws working in a chamfered depression in the lower plate in which they are held by turning a locking plate, as explained by figs. 15 to 20. It is necessary that the extremities or supports of the horizontal axis to the telescope should be precisely on a level with one another when the instrument is set up, otherwise the point of intersection of the webs will not traverse in a true vertical plane.

In a transit class of instrument, reversal of the axis is an essential feature. The permanent adjustments of the instrument executed by the makers fix the horizontal limb marked P truly level, when the spirit bubbles Q and T, or T^1, appear in the centre of their run, they fix also the plane of the vertical arc or circle perpendicular to the horizontal limb. When all the parts of an instrument are received fresh from the hands of the makers, all the screws connected with the permanent adjustments should be nearly home, as want of steadiness under the least rough usage may be the result of such screws being raised too much above their bearings. The line of collimation must also be at right angles to the trunnion axis of the telescope, and the trunnion axis of the telescope should be parallel to the horizontal limb. The long spirit level attached to the telescope should be parallel to the line of collimation (see figs. 34 to 44), and the line of collimation should coincide with the axis of the cylindrical rings in which the telescope turns. This adjustment is effected half by the vertical screws in the diaphragm and half by the screws which elevate or depress the telescope. The instrument needs to be checked in azimuth and altitude, that is, both horizontally and vertically. The line of collimation having

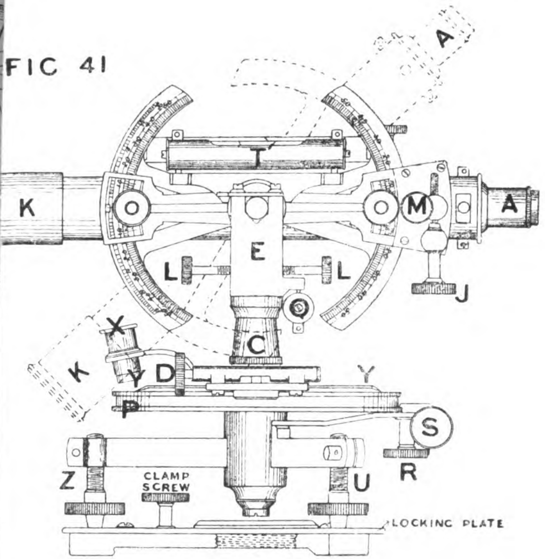
Work and Instruments, pp. 148, 149, 150.

THE THEODOLITE

FIC 39

FOR

FIC 41



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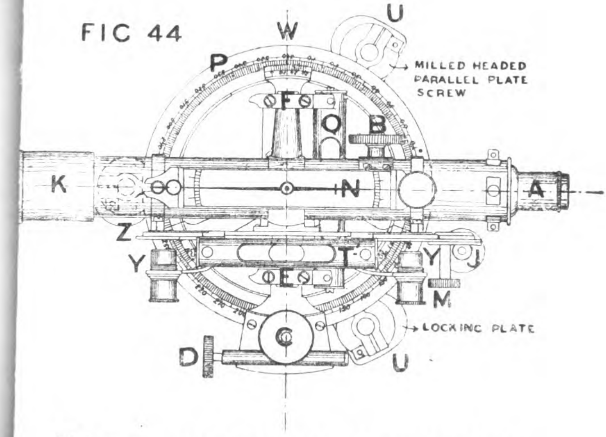

NOTE — VERNIERS AT W. Y. & Y.

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been thus set, the longitudinal bubble should be tested for reversion. To effect a further test of the workmanship of the bearing surfaces connected with the vertical axis, set up the instrument as accurately level as possible, clamp the vernier plate to zero, and turn the limb of the instrument round the vertical axis until the telescope is over two opposite parallel plate screws U U, or Z Z. Tighten the collar R, and finally adjust the bubbles Q and T in the centre of their run by the parallel plate screws. Then unclamp the vernier plate, and turn it half round, so that the telescope, after traversing 180° upon the horizontal circle, is again over the same pair of parallel plate screws. The spirit levels Q and T will now be reversed in position with regard to the parallel plate screws, and if the bubble in each level is not in the centre of its run, the adjustment must be effected, half by turning the capstan-headed screws of the bubble tubes respectively, which connect it to the instrument, and the remaining half by turning the elevating plate screws parallel to which it is placed. The operation must be repeated until each bubble remains accurately in the centre of its run in both positions of the telescope. Having accomplished this, perform the same operation with the vernier plate clamped to the horizontal limb by unclamping the collar R, and again reversing the telescope by traversing it round 180° over the elevating plate screws. If the bubbles do not still remain in the centre of their run, the instrument must be returned to the makers, as it shows that the two parts of the axis upon which the limb and the stage revolve have been inaccurately turned. (See fig. 3 pages 116-118.)

To adjust the horizontality of the circular plates, we may set up the instrument as nearly level as possible, clamp the lower horizontal plate without clamping the upper horizontal plate, then move the upper plate or stage, so that the telescope is in the direction of a line joining two opposite parallel plate screws, and adjust the longitudinal bubble of the telescope to the centre of its run by means of the clamp and tangent screws of the vertical arc. Next turn the upper plate 180° from its former position, so that the longitudinal bubble is reversed end for end over the same parallel plate screws as before. If the bubble should not still remain in the centre of its run, half the difference must be corrected by the two parallel plate screws, and half by the tangent screw to the vertical arc. Repeat the same operation over the other pair of parallel plate screws, and then try the telescope again over the former pair of parallel plate screws, so that the longitudinal bubble remains constantly in the centre of its tube when reversed in either position. The index error of the vertical arc should then be noted, and its deviation from zero applied in the registration of all vertical angles taken. The two small levels upon the vernier plate may now be adjusted by means of their capstan-headed screws, but not until the above adjustment by means of the longitudinal bubble of the telescope has been satisfactorily secured. The horizontal circular plates may next be set level, and the accuracy of the azimuthal axis may be further tested by turning the vernier plate 90° upon its vertical axis, or one-quarter round backwards and forwards, so that the telescope may be over the other parallel plate screws marked Z Z, the centre line joining which is at right angles to the centre line U U, joining those over which the instrument has been tested. (See figs. 3 and 4, pages 116-118.)

However carefully the mechanism of the instrument may be executed, the telescope requires to be tested optically when fitted together. Having examined the permanent adjustments of the instrument below the telescope, attention should always be given to adjust the line of collimation (1) for measuring horizontal angles, or angles in azimuth; (2) for measuring vertical angles.

In order that the telescope may traverse a vertical circle and its line of collimation set out vertical angles or find any number of points in a vertical plane, it is necessary that its trunnion axis should be truly horizontal. It will be observed in fig. 39 (pages 148-150), which represents a transit instrument, that one end of the trunnion axis of the telescope, where it rests in the Y's, is arranged with an adjustable block. This block, which is technically called a slipping-piece, is raised or lowered by turning the capstan-headed nuts attached to its screw connexion with the upright marked E. A long and sensitive spirit-level, called a striding level, intended for testing the level of the pivots of the telescope, and marked H in fig. 4, is placed transversely, spanning the instrument from one trunnion bearing to the other. The feet of the standards to this level are formed of two inverted V-shaped notches filed where they rest on the trunnion, as shown in fig. 3. The telescope is placed diagonally over the parallel plate screws U U, and the instrument set up level. The spirit bubbles Q and T will then be in the centre of their run. To adjust the horizontality of the trunnion axis the spirit-level H is first placed upon the trunnion bearings and set level if it appears out of the centre of its run, by its under parallel plate screws marked Z Z. It is then lifted carefully off and reversed end for end upon the trunnion bearings. A small wooden handle, omitted in fig. 4, is often attached to the centre of this level at H to prevent the heat of the hand affecting the bubble when touching it. The bubble tube being properly graduated, it is at once seen if the bubble remains in the centre of its run. If it deviates when reversed, half the error must be corrected by means of its own capstan-headed adjustment screws and half by the two parallel plate screws beneath it, marked Z Z. The trunnion axis will then be parallel to the run of this level marked H, when it is set level, but in adjusting it for reversion the vernier plate as indicated by the spirit-levels Q and T may have been thrown out of level. The next step, therefore, will be to reset the spirit-levels Q and T in the centre of their run by working the parallel plate screws U U, and Z Z, then raise or lower the slipping-piece in the upright marked E until the bubble in the axis level tube marked H is in the centre of its run. By this means the trunnion axis can be set parallel to the level of the vernier plate, when it will be at right angles to the vertical axis of the instrument, and is thus finally adjusted for reversion.

The measurement of horizontal angles being the most important function of a theodolite, it is best to adjust the collimation first for horizontal planes and the measurement of vertical angles; then, secondly, for vertical planes and the measurement of horizontal angles. By this means the telescope will remain finally adjusted under conditions in which it is most generally employed. When both the horizontal limb and the vernier plate are in adjustment,—that is, when the bubbles of the two spirit-levels Q and T remain in the centre of their run during all positions of the revolution of either the vernier plate or of the whole instrument round the vertical axis, as above determined,—the line of collimation in the telescope should be horizontal when the bubble attached to the telescope is in the centre of its run, with the vertical arc or circle set to zero. The adjustment of this long bubble for reversion is effected in a similar manner to the adjustment of the shorter bubble T, to which it is parallel. The vertical arc is clamped to zero, and the telescope reversed as before.

After the preceding operation has been gone through, set the index of the verniers upon the vertical arc to zero, fix the clamp M, and level the bubble on the telescope by means of the adjacent screws marked L L in figs. 3 and 4. Make the bubble reverse by traversing the horizontal vernier plate half round the vertical axis, and adjust half any error that may exist by means of the screws L L, and the remaining half by means of the capstan-headed screws which connect the longitudinal bubble to the telescope. The telescope, though attached to the horizontal plate and body of the instrument by the connexions marked L L, permits its bubble to be adjusted as here described. Having done this, unclamp the screw M, and point the telescope to some well-defined distant object. Take the angle of altitude or depression of this object, after clamping the arc and bisecting the object viewed with the cross hairs by means of the tangent screw J to the vertical circle. Then reverse the telescope in the Y's, and revolve the instrument half-round horizontally. Repeat the operation of again setting the vertical arc to zero, and level the bubble by the screws L L (fig. 3). Set the telescope upon the point in the object first ranged, and if the vertical angle is found to be the same in both positions, no adjustment of the vertical collimating screws will be necessary, but if the first and second readings do not coincide, set the verniers to the mean angle, taking care all through that the axis bubble H appears perfect, and move the vertical screws upon the diaphragm plate until the intersection of the cross wires accurately cuts the distant point employed for the purpose. If preferred, a distant point upon a level with the line of collimation, when the verniers on the vertical arc read zero and the longitudinal spirit bubble is set in the centre of its run may be used for the purpose instead of a point above or below the horizon.

Horizontal angles between vertical planes.—(*a*). Having set up the instrument level, clamp the horizontal vernier plate to zero, and with the collar R unclamped, direct the telescope to a flagstaff, the weather vane on the spire of a church, or to some small well-defined object, at as great a distance from the instrument as the situation will permit. Then tighten the collar R, and by means of the tangent screw S, make the central intersection of the cross hairs bisect the object viewed. Having done this, release the clamp screw C of the upper plate, and traverse the upper plate from zero, so that a point in another well-defined distant object, which should stand about the same level, is viewed, clamp the screw C, and by means of its tangent screw D, make the cross hairs carefully bisect the second point of observation which has been selected. Then carefully record the horizontal angle traversed, taking the mean of the readings furnished by the verniers, if it is desired to book the angle, so as to ensure accuracy in registering the sub-divisions. Next, before unclamping either the screw C or R, revolve the telescope vertically, in the case of a transit instrument, so that the telescope is turned over, reversing the eye-piece and object-glass end for end; then unclamp the collar R, and turn the whole body of the instrument round 180° in the direction of the last or second object viewed, leaving the vernier plate clamped as at the last reading. Clamp the collar R, and by means of the tangent screw S, make the cross hairs again bisect this object. Then release the vernier plate by unclamping the screw C, and turn the telescope horizontally round in the direction of the first object without unclamping the lower plate. Clamp the upper plate by the screw C, and carefully bisect the first object viewed by working the tangent screw D. If the index of the vernier now points exactly to zero upon the lower plate, the line of collimation is correct, and the horizontal angle read between the two lines of sight can be accurately booked; but if the index of the vernier does not return to zero upon the primary scale of divisions, then half the error must be corrected by the horizontal capstan-headed collimation screws, and half by the tangent screw D. Care must be taken to move the opposite side screws in the diaphragm plate, both in the same direction and equal in amount, so that they should be adjusted gradually, in order to turn one as much as the other. The adjustment of the capstan-headed collimation screws which hold the diaphragm plate is effected by a spindle-piece found in the box, as previously explained.

Method (*a*) may be further tested in the following manner:—After setting the instrument to zero, and finding the horizontal angle between the two distant stations, revolve the telescope vertically, or in the case of a non-transit instrument reverse the trunnion axis. Then unclamp the body of the instrument and traverse it round with the vernier plate clamped at the angle on the primary scale of divisions, which was read before reversing the telescope. Move the telescope in the direction of the first object viewed, and after clamping the body of the instrument, set the cross hairs by means of the tangent screw S, accurately on the point indicating the line of direction from which the angle was first measured. Unclamp the vernier plate and traverse the same angle as before. Fix the clamp C, and set the telescope accurately upon the point indicating the line of the direction of the second object viewed, by working the tangent screw D. If the angle now recorded be greater or less than double the first angle read, the difference must be noted and the error should be corrected without unclamping the plates. The vernier plate is traversed by means of the tangent screw D until the reading of the index shows that the line of sight in the telescope points in the direction of the mean angle. Then, finely adjust by gently turning the horizontal collimation screws which hold the diaphragm plate, until the intersection of the cross hairs bisects the point in the second object under observation. The angle should be re-measured with the telescope in a reversed position to ensure accuracy. If it remains the same in amount as this mean angle, the collimation adjustment of the telescope for angles in azimuth is correct.

(*b*) In a transit instrument, the adjustment of the line of collimation may be tested with the observation of a single station by first bisecting the object viewed after clamping both screws C and R, then revolve the telescope, so that if the bubble was first above the telescope, it is now below it, and then unclamping the screw C, revolve the vernier plate round 180°, reclamp the screw C, adjust the index by the tangent screw D, and proceed as before. (*c*) Another method consists in sighting accurately the centre of a distant object; then without unclamping, or in any way disturbing the position of the instrument, revolve the telescope with great care and mark a position upon the other side of the instrument, which should be on a continuous line in plan. Then without revolving the telescope or releasing the upper plate, undo the lower clamp R and turn the body of the instrument half-round, clamp the lower plate, and by means of the tangent screw S make the cross hairs bisect the first position viewed. Again, revolve the telescope vertically without unclamping the instrument, and if the cross hairs now bisect the second point observed on the line produced, the instrument is in adjustment for taking horizontal angles on or upon the same levels, but if not, note the error, and adjust the horizontal screws in the diaphragm plate so that the line of sight may strike half-way between the two points observed upon this side of the line. Repeat the test to prove the accuracy of the adjustment for the measurement of angles in azimuth. In the case of a non-transit instrument, such as a plain or an Everest theodolite, the vernier plate is first clamped to zero as before. The cross wires are set to bisect some well-defined distant object by means of the clamping and adjusting arrangements, R and S. The telescope is lifted gently out of its bearings, and replaced very carefully with the trunnion axis reversed. The screw C is then unclamped, and the vernier plate traversed through 180°. The screw C is again clamped, and the vernier index finally adjusted by the tangent screw D. If the object viewed be still bisected, it proves that the line of collimation is perpendicular to the trunnion axis; but if not, then the error must be corrected, as above explained. Having done this to ascertain if half the error of deviation has been correctly estimated, again traverse the telescope or reverse the trunnion axis, and if the line of collimation does not still bisect the object viewed, the operation must be repeated until, by successive approximations, the object is found to be accurately bisected in both positions of the trunnion axis.

In the methods described as (*a*) and (*c*) two distant points or stations are required. The points ranged by method (*a*) are both in front of the instrument, and the angle between their directions is observed before and after reversing the telescope upon its trunnion axis, and after traversing the body of the instrument half-round upon its vertical axis with the vernier plate clamped. In method (*c*) the points ranged are upon opposite sides of the instrument. If the surveyor is satisfied that the trunnion axis of the telescope properly reverses over the vernier plate when the latter is set level, and that the vertical capstan-headed screws in the diaphragm plate need no adjustment, then it is not necessary for the two objects viewed to stand upon the same level. In method described as (*b*) a single station, at as great a distance as possible, is sufficient. The line of collimation is set upon the point selected, and the readings upon the vernier plate are taken both before and after reversing the trunnion axis or traversing the telescope round vertically end for end, but instead of the body of the instrument being traversed half-round, as in methods (*a*) and (*c*), the vernier plate is traversed half-round from the position shown in fig. 39 to the position shown in fig. 40 (pages 148-150).

The student who has carefully followed the above description of adjustments, viewed from all sides, ought to have no difficulty in applying the theodolite to the various classes of work for which it is suitable, and although he would leave many of these permanent adjustments to the maker, he should be in a position to realise their importance and to be acquainted with their effect.

Metford's Theodolite.—This is an instrument in which three screws for levelling, in place of the ordinary parallel plate screws, are used.

It has a traversing plate with a motion of one inch from its centre in any direction, the object of which is to enable the observer to shift his instrument over the exact centre after having set it up firmly, nearly level, and approximately over the point required; by its use there is a saving of time when the instrument has to be frequently set up in the course of a day. The telescope attached to the vertical circle admits of a transit motion.

On the horizontal limb of the instrument is fixed a circular bubble, by its means the instrument can be set nearly level in both planes by shifting either of the legs, this can be done with great accuracy, so much so that the three adjusting screws require but slight alteration to perfect the adjustment.

The same staff head is used as in Pastorelli's patent levels (see pages 202, 203).

The edge of the horizontal limb is made angular, by which readings can be taken with greater facility.

CHAPTER XVI.

LEVELS.

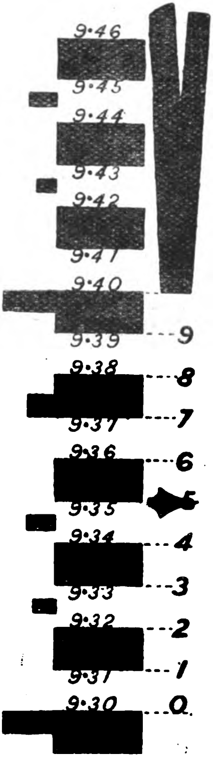
LEVELLING has been defined as "the art of finding a line parallel to the horizon at one or more stations, in order to assign the difference of altitude between one place and another." In a comprehensive sense, the word "surveying" includes "levelling," but in a restricted sense, the former term refers only to the plan, and is used to express the art of taking such horizontal measurements as will enable the Surveyor accurately to represent upon a plane surface such objects as exist in the field or area dealt with, while the art of levelling determines the rise and fall of the ground, and is connected mainly with the vertical measurements required for a section in a vertical plane. The knowledge of the detail portions of a Theodolite and its adjustments, will enable the reader the better to understand the use and adjustment of those principal parts which are connected to a level.

The Troughton Level, described in "Heather and Walmisley's Mathematical Instruments," pages 104, 105, possessed the advantage that the long bubble tube was permanently fixed in the upper part of the telescope, and therefore dispensed with adjustments between the tube and the telescope, but it combined the disadvantage that, in the event of the bubble tube becoming fractured, it could only be replaced by the maker. As an instrument, the Troughton level has now become obsolete.

In the Gravatt form of level the telescope forms a part of the body of the instrument. It combines all the advantages of a larger instrument without the inconvenience of its length, and hence in its improved form has acquired the familiar name of "Dumpy Level." The object-glass is of large aperture, but of comparatively short focal length, by which means sufficient light is obtained to allow of a high magnifying power in the eye-piece. Consequently more rays of light are admitted to the eye, producing the advantages of greater distinctness, which is confined by the introduction of stop-pieces, arranged in such positions with central openings of diameter only sufficient to allow those rays which are included within the cone of vision converged by the object-glass to reach the common focus of the object-glass and eye-piece at the intersection of the cross hairs in the diaphragm-plate. The magnifying power of a telescope is found by dividing the distance between the diaphragm and the nearest surface of the object-glass by the focal length of the combined eye-piece. Thus for the two eye-pieces described in page 89, if 10 = the focal length of the object-glass in inches, we have $\frac{10}{\cdot 843} = 12$ in one case and $\frac{10}{\cdot 5625} = 17\frac{3}{4}$ in the other case. When looking through the telescope from the eye end, with the eye-piece removed, the eye being near the focus of the object-glass, the whole of the object-glass should be seen, and all parts of the intervening tube concealed, otherwise the stops are not properly fixed. The inside of the tube and stops are covered with a dull black pigment, in order that no light may be reflected by its surface. The inverting eye-piece secures a clearness of vision in a telescope which can not be obtained with an erect eye-piece, the latter having four lenses, as shown in fig. 6, page 82, and the inverting eye-piece only two lenses. Fig. 1 shows a detailed explanation of the decimal divisions upon a level staff (see fig. 2). Fig. 3 shows the amount of field included in the vision under ordinary circumstances. With the use of a positive eye-piece, an inverted image at the common focus of the object-glass and eye-piece is formed within the diaphragm-plate, as explained on page 88, and the staff is read upon the horizontal line in which this focus appears.

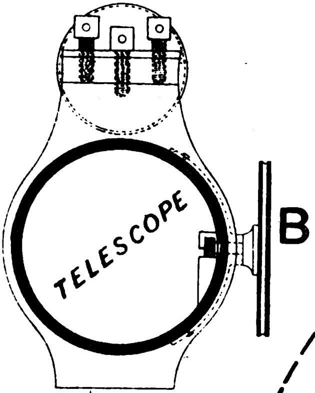
Troughton & Simms' Level.—Fig. 1 (pages 168, 169) shows the fixed telescope of a dumpy level, consisting of an outer tube carrying the object-glass and an inner tube carrying the diaphragm and the eye-piece. The milled head marked B turns a small pinion wheel, which works in a rack fixed inside the inner tube, as shown in fig. 6. By this means the inner tube is drawn backwards and forwards in a horizontal line when the longitudinal bubble is in the centre of its run. This bubble is fastened to the telescope at the supports marked U, its fixed position being determined by the instrument-makers, primarily by filing the underside of the pieces attached to each end, through which the connecting screws marked C and Q pass, and finally by adjusting, if necessary, the side screws marked Z Z. In the case of a new bubble tube being inserted, the screws Z Z are called into use, and serve to accurately fix the new longitudinal glass tube, so that the bubble will run level in a transverse direction. A short transverse bubble marked F is usually attached to the telescope to indicate the horizontality of the run of the longitudinal bubble in a direction at right angles to its length. The use of a transverse bubble to facilitate the approximate setting up of a level was the idea of Mr. Gravatt. Messrs. Troughton & Simms, Messrs. Elliott, Messrs. Casella, and other well-known makers have sought improvements, but in the writer's opinion a transverse bubble is only of service when a compass is added to an instrument, and it is better to rely upon the more sensitive run of the long bubble in two directions, one at right angles to the other, as will be explained when dealing with the setting up the instrument in the field. The screws by which the longitudinal bubble is attached to the telescope have capstan heads at C and slot heads at Q. The capstan heads are preferred by the makers, but the position of the transverse bubble necessitates the substitution of slot-head screws at Q. The cross-hairs upon the diaphragm are arranged as shown in fig. 4, and the diaphragm plate is attached to the internal tube of the telescope by the vertical collimation adjustment screws marked R R. No horizontal adjustment screws being required for the collimation adjustment of a level, the diaphragm plate is held in the side frames shown in fig. 3, between which, it can be moved up and down. The transverse bubble can be accurately fitted level by the makers when the longitudinal bubble is in adjustment, and by the aid of the transverse bubble, the makers are enabled to ascertain if the horizontal cross-wire is truly horizontal. The external tube of the telescope is sprung at the eye-piece end, between the eye-piece and the support marked U, by slots in the top surface, as shown in fig. 1 (pages 168, 169). A steady and even motion can thus be imparted to the inner tube when drawing it in and out for the purpose of adjusting the focus of objects at different distances from the instrument. The inner tube is nearly equal in length to the outer tube, and carries the stop-pieces marked M and P for limiting the rays of light to the cone of rays formed between the circumference of the object-glass and its principal focus in the diaphragm plate. The stop-pieces are formed of circular discs with a hole of calculated diameter in the centre. They cut off scattered rays not necessary for the formation of the imaginary image. The effect of drawing the inner tube out is to lengthen the focus of the object-glass. When the object viewed is at a short distance from the observer, the operator is compelled to bring the wires of the instrument under adjustment for focal distance farther away from the object-glass, and to move them nearer the object-glass when the object is at a greater distance. Two Ramsden eye-pieces marked A are supplied with the instrument—a long eye-piece and a short eye-piece. The uses of these eye-pieces have already been described. The gain of power in one is attended with a comparative loss of light. The supports to the telescope marked U U are fixed to a horizontal rigid bar marked V by a hinged joint at E, and by an adjusting screw connexion at D (fig. 1). Between the supports U U, sufficient room is provided in the horizontal connexion for a compass-box, marked J, to be inserted if desired. In some instruments this space is occupied with a small circular level, by means of which the instrument can be approximately set up at once, with the vertical axis at right angles to the horizon. The upper portion of the instrument containing the stage or horizontal bar, which carries the telescope, revolves upon the body of the instrument marked N. The upper parallel plate forms a portion of this body-piece, and is supported by the elevating screws marked G and H, its centre being connected to

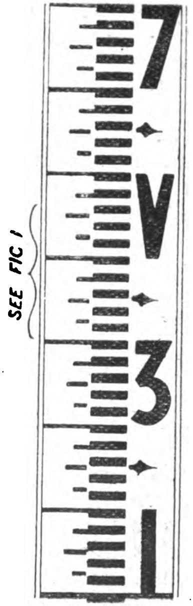
FIG 1



ENLARGEMENT
SHOWING
STAFF READINGS

FIG 2





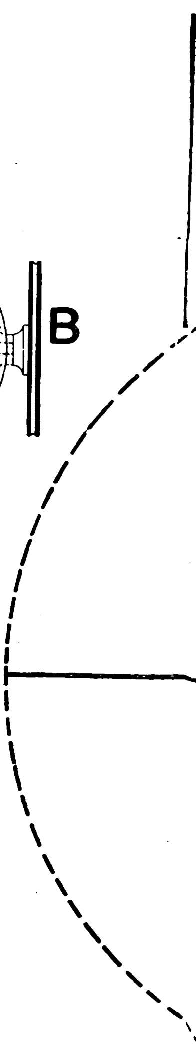
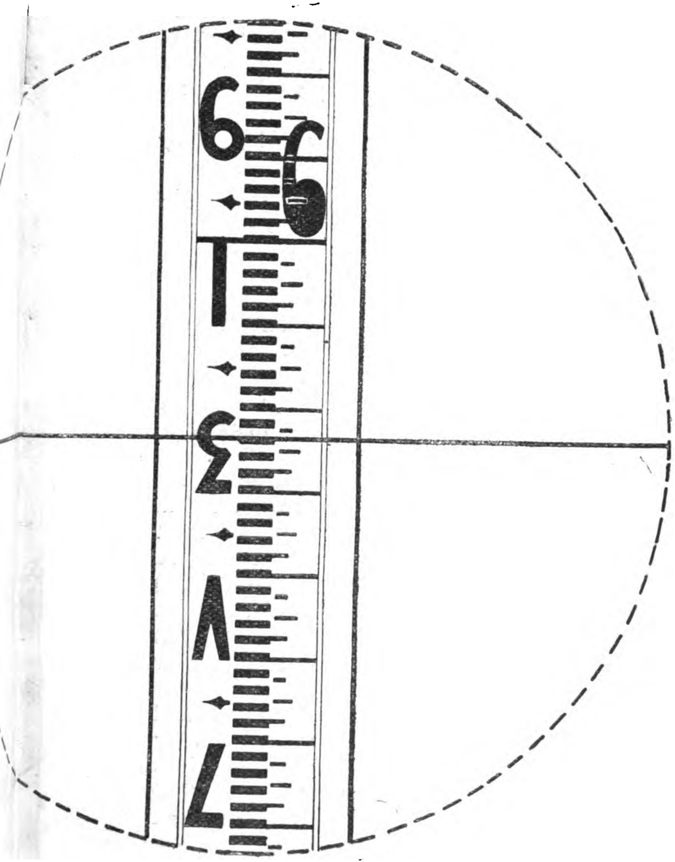


DIAGRAM ILLUSTRATING THE RE

[*Field Work and Instruments, pp.* 164, 165.

FIG 3



READINGS UPON A LEVEL STAFF

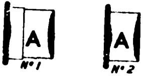
the lower parallel plate at O by the half ball-and-socket joint, as shown in fig. 1. The stop-block marked T prevents the upper parallel plate revolving upon the lower parallel plate. Sometimes the telescope is constructed to be detached from the parallel plates, when not in use, for convenience of packing, but some makers prefer to permanently fix it to the bearing-piece which surrounds the body of the instrument marked N.

The Level in the Field.—In order to avoid straining the parallel plate-screws, the instrument is first set up as nearly level as possible by working one of the legs of the tripod stand, as explained below, and then finally adjusting the longitudinal bubble by means of the parallel plate-screws. The method adopted is as follows:—Move the telescope till it lies in the direction of two opposite plate-screws, as shown in fig. 1 (pages 171-173), and then select the most convenient leg of the tripod to work with. If the leg marked as No. 2 be chosen and the legs marked as No. 1 and No. 3 be regarded as fixed on the ground, notice the end to which the bubble retires, and lift the leg marked as No. 2 just clear of the ground, so as to be able to shift it either to the right or the left hand in the direction of the curved arrows, until the bubble appears approximately in the centre of its run. Then twist the telescope a quarter round, until it assumes the position shown in fig. 2 over the other two parallel plate-screws, and shift the same leg (No. 2) in a line approximately at right angles to the direction in which it was moved in fig. 1, as indicated by the straight arrows, until the bubble appears in the centre of its run, or nearly so in this direction. Turn the telescope back to the position shown in fig. 1, and repeat the adjustment indicated by the curved arrows. Then complete the correction by the parallel plate-screws with the telescope in both positions (figs. 1 and 2), as shown upon pages 171-173. The level is set up in the most convenient position, and as far as the situation will permit, midway between the first and last sights to be taken with the instrument in any single position but generally off the line of section to be taken, as the place of the staff is localised, not the place of the level. Upon sidelong ground it is well to keep upon the high side of the line along which levels are being taken, the height of the instrument above the ground being limited by the length of the tripod legs, whereas the length of the level staff usually provides a limit of at least three times that length. The height at which the level itself is set up does not affect the result, but care must be taken that the line of sight does not range above the top of the level staff, or cut the ground below its foot. When the staff is at a distance of, say, 22 feet or one-third of a chain or less from the instrument, it frequently happens that the line of collimation cuts the subdivisions upon its face, midway between the divisions usually figured in red, which indicate feet, in such a way as to render these red figures invisible within the cone of rays proceeding through the telescope. When this occurs, the sub-divisions upon the staff may be read with the inner tube of the telescope completely drawn out, but it becomes necessary for the surveyor either to direct the staff-holder to raise the staff slowly, or to revolve it back some distance, in order that the figure indicating feet may be correctly read. To obviate this, Harling's exterior sights, as shown in figs. 3 and 4 (pages 171-173), are useful. They are also of service for roughly determining the approximate levels of ground, when the weather is too dusk or misty to observe clearly through the telescope; and for levelling when great accuracy in the registration of the subdivisions is not important. The lower end of the level staff is invariably shod with brass.

It is important in continuous levelling that the staff should be held over the same spot before and after changing the position of the level. Upon hard ground a small metal plate, as shown in fig. 5 (pages 171-173) is generally employed for this purpose, the chain which is attached to it being for the convenience of the staff-holder in lifting it from the ground and carrying it from one change station to another. Some have a spherical boss in the centre, upon the top of which the staff is held. Upon soft ground, the form of iron peg shown in fig. 7 is preferable, the peg being put into the ground by the staff-holder, and then made firm by pressing the flat plate with his foot. The square top of this station peg forms a very

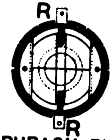
TROUGHTO

Fig 2

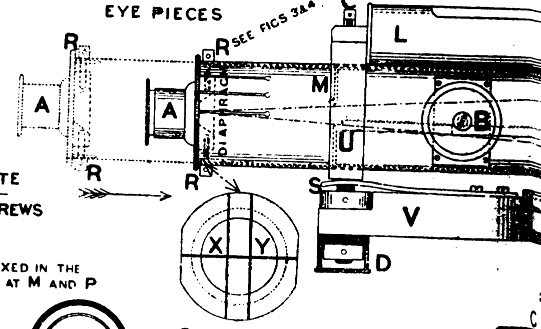


EYE PIECES

Fig 3



DIAPHRAGM PLATE
— SHOWING —
ADJUSTMENT SCREWS



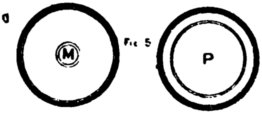
DIAPHRAGM
ENLARGED VIEW

Fig 4

R COLLIMATION SCREWS

D REVERSION SCREWS

STOPS FIXED IN THE
TELESCOPE AT M AND P

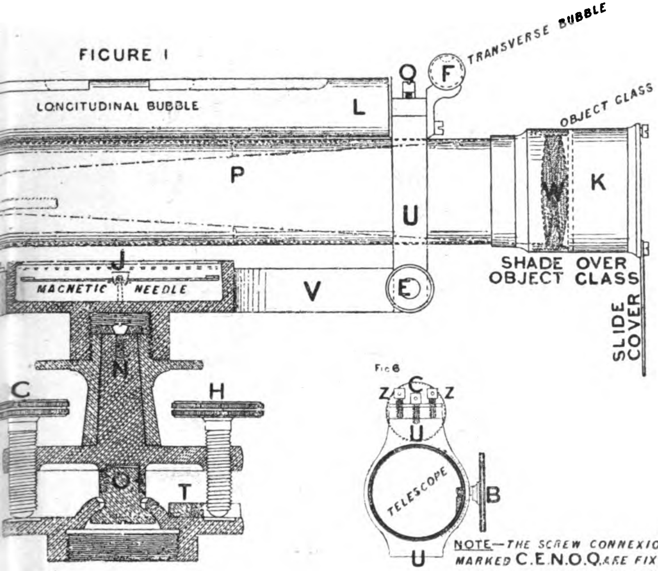


NOTE — IN ADJUSTING THE LONGITUDINAL BUBBLE FOR REVERSION, HALF THE ERROR IS CORRECTED BY THE CAPSTAN SCREW D, *WHICH RAISES OR LOWERS THE SPRING* S, *SUPPORTING THE END NEAR THE EYEPIECE; AND WHICH IS SECURED BY THE LOCK NUT PLACED ABOVE THE CONNECTING STAGE* V. *—— THE REMAINING HALF OF THE ERROR IS ADJUSTED BY THE OPPOSITE PARALLEL PLATE SCREWS* C *AND* H, *OVER WHICH THE TELESCOPE IS REVERSED BY REVOLVING 180 DEGREES UPON ITS AXIS.*

[*Field Work and Instruments, pp.* 168, 169.

TON & SIMMS'S LEVEL

FIGURE I



NOTE—*THE SCREW CONNEXIONS MARKED* C.E.N.O.Q. *ARE FIXED BY THE INSTRUMENT MAKER, AND ARE NOT INTENDED FOR ANYONE EXCEPT AN INSTRUMENT MAKER TO ADJUST.—WHEN ONCE FIXED NO SUBSEQUENT ALTERATION WILL BE NEEDED, UNLESS THE INSTRUMENT SUSTAIN INJURY* ———

reliable temporary bench mark for securing accuracy in the position in which the staff is held. When the telescope of a level is directed towards the staff, it is first adjusted to focus by means of the draw-tube worked by the rack-and-pinion motion, and the longitudinal bubble is next observed and set accurately in the centre of its run by working (if necessary) the two opposite parallel plate-screws which come nearest in the direction of the telescope. If the adjustment for reversion is correct, no more than a very slight movement of these screws should be necessary when the instrument has been properly set up. If the line of collimation is truly horizontal, the number of feet and decimals of a foot at which the horizontal cross-hair of the diaphragm appears to cross the inverted readings on the face of the level staff will show the height of the line of collimation above the point on which the staff is held; but in order that this amount may accurately furnish the vertical depth of the point upon which the lower end of the staff stands, it is necessary that the staff be read when plumb, *i.e.*, in a line perpendicular to the plane of standing water, and this can be best effected by instructing the staff-holder to wave the staff towards and from the instrument over this line in a vertical plane, as shown in fig. 6 (pages 171-173). The shortest reading will then express the amount to be booked. When the line of sight cuts across a division upon the staff and the surveyor is in doubt which subdivision to book, it is found by experience that the most accurate final results are obtained by booking the shortest or lowest reading.

The Y Level.—In the Y form of level the instrument can be checked for collimation and adjustment in the field from time to time during operations. The telescope rests in the Y shaped bearings (fig. 5, pages 174-176) which give the instrument its distinctive name, and it is reversible in its Y supports, end for end, so that it is immaterial in which Y, the object-glass end or the eye-piece end is held. The accuracy of the instrument depends upon the line of collimation being coincident with the axis of the telescope and upon the collars being both vertically and horizontally parallel to the telescopic tubes. Fig. 3 illustrates an end view of the Y support, open ready

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to receive the telescope. Fig. 5 gives an enlarged view of the Y support, showing one of the collars which surround the outer tube of the telescope. In order to test the accuracy of the line of collimation the instrument is set up approximately level, and a well-defined distant point observed. If a level staff is held at as great a distance from the instrument as may be found convenient for clearly reading the divisions upon the face of the staff, the height read with the telescope in the position shown in fig. 1 should be the same as the height read when the telescope is revolved vertically round in its bearings 180°, to the position shown in fig. 2. If any difference exists, the diaphragm plate must be adjusted by moving the vertical capstan-headed screws near the eye-piece marked A and B in figs. 1 and 2, until the staff reads the same with the telescope in both positions. Before revolving the telescope upon its axis from the position shown in fig. 1 to the position shown in fig. 2, the clamp-screw attached to the body of the instrument should be tightened, and while revolving the telescope let it be observed whether the centre point between the two vertical cross-hairs diverges to the right or left hand of the distant point chosen for observation. Place the telescope, as shown in fig. 4, with the single cross-hair vertical, and observe a distant point. Revolve it 180°, as before, and the total divergence horizontally will then be apparent. Half this amount must then be taken up by working the same capstan-headed screws, A and B, which are now in a horizontal position, in order to correct any error that exists in this direction. The adjustment of the parallel cross-hairs with reference to the single cross-hair is effected by the capstan-headed screws marked C and D.

Next, to make the run of the longitudinal bubble parallel to the axis of the telescope, so that when the longitudinal bubble properly reverses, the line of collimation within the telescope may be set level by it. Unfasten the Y clips and place the telescope exactly over two opposite parallel plate screws. Tighten the clamp screw and set the longitudinal bubble in the centre of its run by the parallel plate screws. Lift the telescope out of the Ys and replace it with the ends reversed, so that the object-glass end would be removed to

the left-hand side, and the eye-piece end to the right side in fig. 1. Then adjust any error that may appear in the level of the longitudinal bubble, half by the two parallel plate screws over which the telescope has been placed, and half by the capstan-headed nut and lock nut marked F, which together raise or lower one end of the bubble tube, as required upon its vertical screw-attachment to the telescope. Having done this, we have in the third place to set the axis of the telescope at right angles to the vertical axis of the instrument, so that the line of collimation may traverse in a horizontal plane. This is effected with the telescope fixed in the Y's, as shown in fig. 1. The clamp screw is slack, and the longitudinal bubble set level with the telescope placed over two opposite parallel plate screws. The instrument is then turned half round upon its vertical axis, so that the contrary ends of the telescope and the Y supports have changed places over the same two parallel plate screws. If the bubble is not found to settle in the centre of its run after traversing half round horizontally, half the error must be corrected by the two parallel plate screws over which the telescope has been placed, and the remaining half by the capstan-headed nut marked E attached to the Y shown in the illustration under the horizontal bar next the eye-piece. This adjustment determines the relation of the bubble to the Y supports in one direction. The operation should also be performed over the other two parallel plate screws with the telescope horizontally at right angles to the last direction, and repeated over both directions, until the bubble remains in the centre of its run during a complete traverse of the telescope. When once in order the instrument will remain in adjustment, unless shaken by severe handling in transit by carriage from one place to another. (See pages 174-176.)

Levelling.—It is necessary to define each point in detail where the staff is held, which cannot be done so accurately when a long distance intervenes between the instrument and the level staff. If the distance between the more distant staff and the instrument be considerable, allowance must be made for the curvature of the earth and for refraction. The necessity of correcting for curvature is partly obviated

by the effects of refraction which as already explained has the effect of elevating the apparent position of any object above its real position. The effect of taking the apparent instead of its true level is to render the level of the point, to which observation is made, lower, with reference to the point from which observation is taken, than it really is, so that correction for curvature should be added to a rise and subtracted from a fall. The mean correction due to terrestrial refraction is always subtractive and from observed altitudes is $\frac{1}{1262}$ of the angle subtended by the stations from the centre of the earth. The results of a large number of calculations establish the following averages as correct:—

$$\text{Co-efficient of refraction}\begin{cases} = \cdot 0809 \text{ for rays crossing the sea.} \\ = \cdot 0750 \quad ,, \qquad ,, \qquad \text{land.} \end{cases}$$

The correction for curvature, equal to the square of the distance between the stations divided by the earth's diameter, being about 8 inches for 1 mile, it would amount to four times that quantity or 32 inches for two miles, and 72 inches or nine times that amount for three miles. Approximately it may therefore be stated as two-thirds of a foot for one mile or curvature in feet equals two-thirds of the distance in miles, squared; but although this expression is approximate, it must be remembered that the refraction by which the error of 8 inches per mile is reduced, is a refraction which varies with temperature and barometric pressure. Being only one-tenth of a foot in thirty-one Gunter's chains, no correction is required for short distances, and it becomes practically eliminated when the level is planted midway between the two staff readings. In a continuous system of levelling, the amount of error corrects itself, as it is not advisable to read the staff at a greater distance than the surveyor finds convenient for giving the staff holder full instructions.

The effects of curvature and refraction are practically inappreciable under a distance of ten chains (660 feet). In ordinary levelling the staff is seldom read at so great a distance, indeed an experienced surveyor would change the position of the instrument to secure accuracy, especially as the sub-divisions in the upper length of a telescopic staff being more cramped in width, sub-divisions due to the

reduced width of the top of the staff would become very difficult to read at a long distance.

The annexed diagrams illustrate four different forms of level books. The same readings upon the level staff are used in each case (pages 180-183) in order that the reader may be able to compare the merits of each form of level book. In form

LEVEL BOOK — No. 1

F.L. H.I.

DISTANCES	STAFF	REDUCED LEVELS	LINE OF COLLIMATION	REMARKS
—	3·71✓		117·94 121·65	
0	5·06	116·59		
200	7·88×	113·77		
—	9·40✓		123·17	
375	10·20	112·97		
400	12·30	110·87		
414	13·89×	109·28		
—	3·87✓		113·15	
426	11·71×	101·44		
—	2·63✓		104·07	
433	12·41×	91·66		
—	14·62✓		106·28	
450	8·95	97·33		
475	0·85×	105·43		
—	4·47✓		109·90	
—	2·99	106·91		
510	5·06×	104·84		
—	6·72✓		111·56	
—	2·25	104·31		
512	8·36	103·20		
516	4·59	106·97		
520	5·12×	106·44		
—	6·95✓		113·39	
540	7·28	106·11		
560	7·60	105·79		
580	7·80	105·59		
600	8·29×	105·10		
	52·37✓ 65·21×	12·84 117·94		

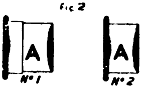
No. 1 all the staff readings are entered in the same column. This system shows the successive readings of the level staff at each setting up of the level, and gives the order in which

LEVEL BOOK No. 2

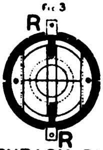
BACK SIGHT	FORE SIGHT	RISE	FALL	REDUCED LEVELS	LENGTHS	REMARKS
3·71				117·94	B.M.	
5·06	5·06		1·35	116·59	0	
9·40	7·88		2·82	113·77	200	
10·20	10·20		0·80	112·97	375	
12·30	12·30		2·10	110·87	400	
3·87	13·89		1·59	109·28	414	
2·63	11·71		7·84	101·44	426	
14·62	12·41		9·78	91·66	433	
8·95	8·95	5·67		97·33	450	
4·47	0·85	8·10		105·43	475	
2·99	2·99	1·48		106·91	—	
6·72	5·06		2·07	104·84	510	
7·25	7·25		0·53	104·31	—	
8·36	8·36		1·11	103·20	512	
4·59	4·59	3·77		106·97	516	
6·95	5·12		0·53	106·44	520	
7·28	7·28		0·33	106·11	540	
7·60	7·60		0·32	105·79	560	
7·80	7·80		0·20	105·59	580	
	8·29		0·49	105·10	600	
134·75	147·59	19·02	31·86			

the staff readings booked in forms Nos. 2, 3, and 4 are taken. In forms Nos. 2 and 3 the staff readings are divided into back-sights and fore-sights, all readings after the first

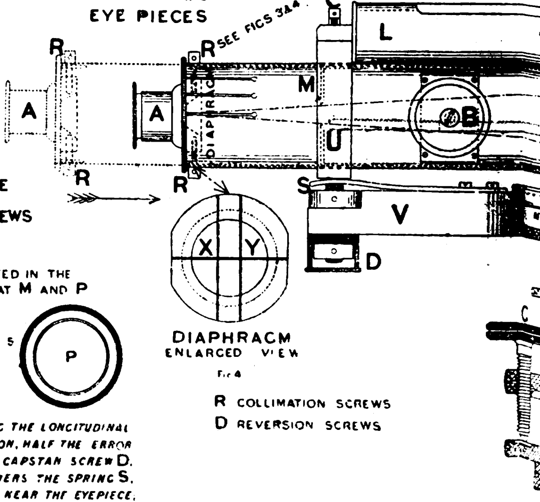
TROUGHTO



EYE PIECES



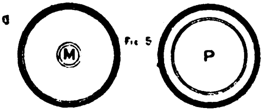
DIAPHRAGM PLATE
— SHOWING —
ADJUSTMENT SCREWS



DIAPHRAGM
ENLARGED VIEW
Fig 4

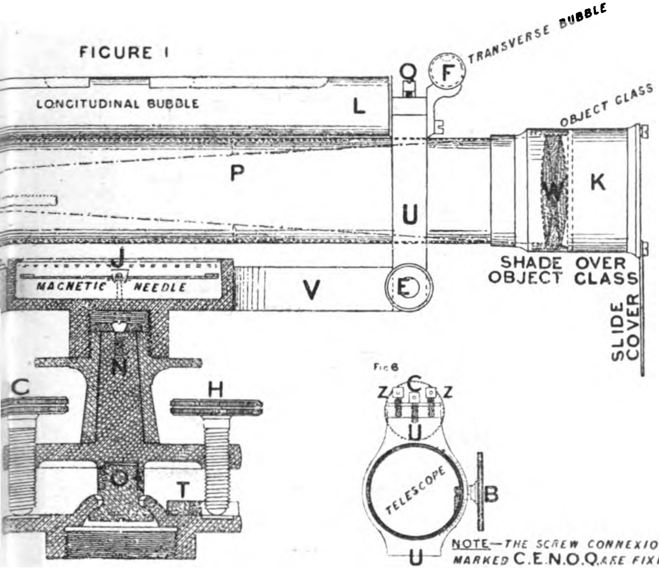
R COLLIMATION SCREWS
D REVERSION SCREWS

STOPS FIXED IN THE TELESCOPE AT M AND P



NOTE — *IN ADJUSTING THE LONGITUDINAL BUBBLE FOR REVERSION, HALF THE ERROR IS CORRECTED BY THE CAPSTAN SCREW* D. *WHICH RAISES OR LOWERS THE SPRING* S. *SUPPORTING THE END NEAR THE EYEPIECE, AND WHICH IS SECURED BY THE LOCK NUT PLACED ABOVE THE CONNECTING STAGE* V. —— *THE REMAINING HALF OF THE ERROR IS ADJUSTED BY THE OPPOSITE PARALLEL PLATE SCREWS* C *AND* H, *OVER WHICH THE TELESCOPE IS REVERSED BY REVOLVING 180 DEGREES UPON ITS AXIS.*

TON & SIMMS'S LEVEL



NOTE—THE SCREW CONNEXIONS MARKED C.E.N.O.Q. ARE FIXED BY THE INSTRUMENT MAKER, AND ARE NOT INTENDED FOR ANYONE EXCEPT AN INSTRUMENT MAKER TO ADJUST.—WHEN ONCE FIXED NO SUBSEQUENT ALTERATION WILL BE NEEDED, UNLESS THE INSTRUMENT SUSTAIN INJURY ——

reliable temporary bench mark for securing accuracy in the position in which the staff is held. When the telescope of a level is directed towards the staff, it is first adjusted to focus by means of the draw-tube worked by the rack-and-pinion motion, and the longitudinal bubble is next observed and set accurately in the centre of its run by working (if necessary) the two opposite parallel plate-screws which come nearest in the direction of the telescope. If the adjustment for reversion is correct, no more than a very slight movement of these screws should be necessary when the instrument has been properly set up. If the line of collimation is truly horizontal, the number of feet and decimals of a foot at which the horizontal cross-hair of the diaphragm appears to cross the inverted readings on the face of the level staff will show the height of the line of collimation above the point on which the staff is held; but in order that this amount may accurately furnish the vertical depth of the point upon which the lower end of the staff stands, it is necessary that the staff be read when plumb, *i.e.*, in a line perpendicular to the plane of standing water, and this can be best effected by instructing the staff-holder to wave the staff towards and from the instrument over this line in a vertical plane, as shown in fig. 6 (pages 171-173). The shortest reading will then express the amount to be booked. When the line of sight cuts across a division upon the staff and the surveyor is in doubt which subdivision to book, it is found by experience that the most accurate final results are obtained by booking the shortest or lowest reading.

The Y Level.—In the Y form of level the instrument can be checked for collimation and adjustment in the field from time to time during operations. The telescope rests in the Y shaped bearings (fig. 5, pages 174-176) which give the instrument its distinctive name, and it is reversible in its Y supports, end for end, so that it is immaterial in which Y, the object-glass end or the eye-piece end is held. The accuracy of the instrument depends upon the line of collimation being coincident with the axis of the telescope and upon the collars being both vertically and horizontally parallel to the telescopic tubes. Fig. 3 illustrates an end view of the Y support, open ready

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to receive the telescope. Fig. 5 gives an enlarged view of the Y support, showing one of the collars which surround the outer tube of the telescope. In order to test the accuracy of the line of collimation the instrument is set up approximately level, and a well-defined distant point observed. If a level staff is held at as great a distance from the instrument as may be found convenient for clearly reading the divisions upon the face of the staff, the height read with the telescope in the position shown in fig. 1 should be the same as the height read when the telescope is revolved vertically round in its bearings 180°, to the position shown in fig. 2. If any difference exists, the diaphragm plate must be adjusted by moving the vertical capstan-headed screws near the eye-piece marked A and B in figs. 1 and 2, until the staff reads the same with the telescope in both positions. Before revolving the telescope upon its axis from the position shown in fig. 1 to the position shown in fig. 2, the clamp-screw attached to the body of the instrument should be tightened, and while revolving the telescope let it be observed whether the centre point between the two vertical cross-hairs diverges to the right or left hand of the distant point chosen for observation. Place the telescope, as shown in fig. 4, with the single cross-hair vertical, and observe a distant point. Revolve it 180°, as before, and the total divergence horizontally will then be apparent. Half this amount must then be taken up by working the same capstan-headed screws, A and B, which are now in a horizontal position, in order to correct any error that exists in this direction. The adjustment of the parallel cross-hairs with reference to the single cross-hair is effected by the capstan-headed screws marked C and D.

Next, to make the run of the longitudinal bubble parallel to the axis of the telescope, so that when the longitudinal bubble properly reverses, the line of collimation within the telescope may be set level by it. Unfasten the Y clips and place the telescope exactly over two opposite parallel plate screws. Tighten the clamp screw and set the longitudinal bubble in the centre of its run by the parallel plate screws. Lift the telescope out of the Ys and replace it with the ends reversed, so that the object-glass end would be removed to

the left-hand side, and the eye-piece end to the right side in fig. 1. Then adjust any error that may appear in the level of the longitudinal bubble, half by the two parallel plate screws over which the telescope has been placed, and half by the capstan-headed nut and lock nut marked F, which together raise or lower one end of the bubble tube, as required upon its vertical screw-attachment to the telescope. Having done this, we have in the third place to set the axis of the telescope at right angles to the vertical axis of the instrument, so that the line of collimation may traverse in a horizontal plane. This is effected with the telescope fixed in the Y's, as shown in fig. 1. The clamp screw is slack, and the longitudinal bubble set level with the telescope placed over two opposite parallel plate screws. The instrument is then turned half round upon its vertical axis, so that the contrary ends of the telescope and the Y supports have changed places over the same two parallel plate screws. If the bubble is not found to settle in the centre of its run after traversing half round horizontally, half the error must be corrected by the two parallel plate screws over which the telescope has been placed, and the remaining half by the capstan-headed nut marked E attached to the Y shown in the illustration under the horizontal bar next the eye-piece. This adjustment determines the relation of the bubble to the Y supports in one direction. The operation should also be performed over the other two parallel plate screws with the telescope horizontally at right angles to the last direction, and repeated over both directions, until the bubble remains in the centre of its run during a complete traverse of the telescope. When once in order the instrument will remain in adjustment, unless shaken by severe handling in transit by carriage from one place to another. (See pages 174-176.)

Levelling.—It is necessary to define each point in detail where the staff is held, which cannot be done so accurately when a long distance intervenes between the instrument and the level staff. If the distance between the more distant staff and the instrument be considerable, allowance must be made for the curvature of the earth and for refraction. The necessity of correcting for curvature is partly obviated

by the effects of refraction which as already explained has the effect of elevating the apparent position of any object above its real position. The effect of taking the apparent instead of its true level is to render the level of the point, to which observation is made, lower, with reference to the point from which observation is taken, than it really is, so that correction for curvature should be added to a rise and subtracted from a fall. The mean correction due to terrestrial refraction is always subtractive and from observed altitudes is $\frac{1}{1262}$ of the angle subtended by the stations from the centre of the earth. The results of a large number of calculations establish the following averages as correct:—

$$\text{Co-efficient of refraction} \begin{cases} = \cdot 0809 \text{ for rays crossing the sea.} \\ = \cdot 0750 \quad ,, \quad ,, \quad \text{land.} \end{cases}$$

The correction for curvature, equal to the square of the distance between the stations divided by the earth's diameter, being about 8 inches for 1 mile, it would amount to four times that quantity or 32 inches for two miles, and 72 inches or nine times that amount for three miles. Approximately it may therefore be stated as two-thirds of a foot for one mile or curvature in feet equals two-thirds of the distance in miles, squared; but although this expression is approximate, it must be remembered that the refraction by which the error of 8 inches per mile is reduced, is a refraction which varies with temperature and barometric pressure. Being only one-tenth of a foot in thirty-one Gunter's chains, no correction is required for short distances, and it becomes practically eliminated when the level is planted midway between the two staff readings. In a continuous system of levelling, the amount of error corrects itself, as it is not advisable to read the staff at a greater distance than the surveyor finds convenient for giving the staff holder full instructions.

The effects of curvature and refraction are practically inappreciable under a distance of ten chains (660 feet). In ordinary levelling the staff is seldom read at so great a distance, indeed an experienced surveyor would change the position of the instrument to secure accuracy, especially as the sub-divisions in the upper length of a telescopic staff being more cramped in width, sub-divisions due to the

reduced width of the top of the staff would become very difficult to read at a long distance.

The annexed diagrams illustrate four different forms of level books. The same readings upon the level staff are used in each case (pages 180-183) in order that the reader may be able to compare the merits of each form of level book. In form

—— LEVEL BOOK —— No. 1

F.L. H.I.

DISTANCES	STAFF	REDUCED LEVELS	LINE OF COLLIMATION	REMARKS
—	3·71✓		117·94 121·65	
0	5·06	116·59		
200	7·88×	113·77		
—	9·40✓		123·17	
375	10·20	112·97		
400	12·30	110·87		
414	13·89×	109·28		
—	3·87✓		113·15	
426	11·71×	101·44		
—	2·63✓		104·07	
433	12·41×	91·66		
—	14·62✓		106·28	
450	8·95	97·33		
475	0·85×	105·43		
—	4·47✓		109·90	
—	2·99	106·91		
510	5·06×	104·84		
—	6·72✓		111·56	
—	2·25	104·31		
512	8·36	103·20		
516	4·59	106·97		
520	5·12×	106·44		
—	6·95✓		113·39	
540	7·28	106·11		
560	7·60	105·79		
580	7·80	105·59		
600	8·29×	105·10		
	52·37✓ 65·21×	12·84 117·94		

No. 1 all the staff readings are entered in the same column. This system shows the successive readings of the level staff at each setting up of the level, and gives the order in which

LEVEL BOOK No. 2

BACK SIGHT	FORE SIGHT	RISE	FALL	REDUCED LEVELS	LENGTHS	REMARKS
3·71				117·94	B.M.	
5·06	5·06		1·35	116·59	0	
9·40	7·88		2·82	113·77	200	
10·20	10·20		0·80	112·97	375	
12·30	12·30		2·10	110·87	400	
3·87	13·89		1·59	109·28	414	
2·63	11·71		7·84	101·44	426	
14·62	12·41		9·78	91·66	433	
8·95	8·95	5·67		97·33	450	
4·47	0·85	8·10		105·43	475	
2·99	2·99	1·48		106·91	—	
6·72	5·06		2·07	104·84	510	
7·25	7·25		0·53	104·31	—	
8·36	8·36		1·11	103·20	512	
4·59	4·59	3·77		106·97	516	
6·95	5·12		0·53	106·44	520	
7·28	7·28		0·33	106·11	540	
7·60	7·60		0·32	105·79	560	
7·80	7·80		0·20	105·59	580	
	8·29		0·49	105·10	600	
134·75	147·59	19·02	31·86			

the staff readings booked in forms Nos. 2, 3, and 4 are taken. In forms Nos. 2 and 3 the staff readings are divided into back-sights and fore-sights, all readings after the first

with the level in any single position being entered as fore-sights.

LEVEL BOOK No. 3

BACK SIGHT	FORE SIGHT	RISE	FALL	REDUCED LEVELS	LENGTHS	REMARKS
3·71				117·94	BM	
	5·06		1·35	116·59	0	
9·40	7·88×		2·82	113·77	200	
	10·20		0·80	112·97	375	
	12·30		2·10	110·87	400	
3·87	13·89×		1·59	109·28	414	
2·63	11·71×		7·84	101·44	426	
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6·72	5·06×		2·07	104·84	510	
	7·25		0·53	104·31	—	
	8·36		1·11	103·20	512	
	4·59	3·77		106·97	516	
6·95	5·12×		0·53	106·44	520	
	7·28		0·33	106·11	540	
	7·60		0·32	105·79	560	
	7·80		0·20	105·59	580	
	8·29×		0·49	105·10	600	
52·37	65·21	19·02	31·86			

Intermediate-Sight.—In form No. 4 all readings between the first and last sights before changing the position of the instrument are entered as intermediate-sights.

Back-Sight.—The first sight read off the level staff is booked in forms Nos. 2, 3, and 4, as a back-sight, and gives, as shown in form No. 1, the height of the line of collimation

LEVEL BOOK — No. 4

BACK SIGHT	INTERMEDIATE	FORE SIGHT	RISE	FALL	REDUCED LEVELS	LENGTHS	REMARKS
3·71					117·94	BM	
	5·06			1·35	116·59	0	
9·40		7·88		2·82	113·77	200	
	10·20			0·80	112·97	375	
	12·30			2·10	110·87	400	
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	2·99		1·48		106·91	——	
6·72		5·06		2·07	104·84	510	
	7·25			0·53	104·31	——	
	8·36			1·11	103·20	512	
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	7·28			0·33	106·11	540	
	7·60			0·32	105·79	560	
	7·80			0·20	105·59	580	
		8·29		0·49	105·10	600	
52·37		65·21	19·02	31·86			

in the instrument, above the point upon which the level staff is placed.

Fore-Sight.—In forms Nos. 2 and 3, all sights read off the level staff after the back-sight, and in form No. 4 the

reliable temporary bench mark for securing accuracy in the position in which the staff is held. When the telescope of a level is directed towards the staff, it is first adjusted to focus by means of the draw-tube worked by the rack-and-pinion motion, and the longitudinal bubble is next observed and set accurately in the centre of its run by working (if necessary) the two opposite parallel plate-screws which come nearest in the direction of the telescope. If the adjustment for reversion is correct, no more than a very slight movement of these screws should be necessary when the instrument has been properly set up. If the line of collimation is truly horizontal, the number of feet and decimals of a foot at which the horizontal cross-hair of the diaphragm appears to cross the inverted readings on the face of the level staff will show the height of the line of collimation above the point on which the staff is held; but in order that this amount may accurately furnish the vertical depth of the point upon which the lower end of the staff stands, it is necessary that the staff be read when plumb, *i.e.*, in a line perpendicular to the plane of standing water, and this can be best effected by instructing the staff-holder to wave the staff towards and from the instrument over this line in a vertical plane, as shown in fig. 6 (pages 171-173). The shortest reading will then express the amount to be booked. When the line of sight cuts across a division upon the staff and the surveyor is in doubt which subdivision to book, it is found by experience that the most accurate final results are obtained by booking the shortest or lowest reading.

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Next, to make the run of the longitudinal bubble parallel to the axis of the telescope, so that when the longitudinal bubble properly reverses, the line of collimation within the telescope may be set level by it. Unfasten the Y clips and place the telescope exactly over two opposite parallel plate screws. Tighten the clamp screw and set the longitudinal bubble in the centre of its run by the parallel plate screws. Lift the telescope out of the Ys and replace it with the ends reversed, so that the object-glass end would be removed to

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—— LEVEL BOOK —— Nº 1

R.L. H.I.

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——	3·71✓		117·94 121·65	
0	5·06	116·59		
200	7·88×	113·77		
——	9·40✓		123·17	
375	10·20	112·97		
400	12·30	110·87		
414	13·89×	109·28		
——	3·87✓		113·15	
426	11·71×	101·44		
——	2·63✓		104·07	
433	12·41×	91·66		
——	14·62✓		106·28	
450	8·95	97·33		
475	0·85×	105·43		
——	4·47✓		109·90	
——	2·99	106·91		
510	5·06×	104·84		
——	6·72✓		111·56	
——	2·25	104·31		
512	8·36	103·20		
516	4·59	106·97		
520	5·12×	106·44		
——	6·95✓		113·39	
540	7·28	106·11		
560	7·60	105·79		
580	7·80	105·59		
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	52·37✓ 65·21×	12·84 117·94		

No. 1 all the staff readings are entered in the same column. This system shows the successive readings of the level staff at each setting up of the level, and gives the order in which

LEVEL BOOK N°. 2

BACK SIGHT	FORE SIGHT	RISE	FALL	REDUCED LEVELS	LENGTHS	REMARKS
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5·06	5·06		1·35	116·59	0	
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3·87	13·89		1·59	109·28	414	
2·63	11·71		7·84	101·44	426	
14·62	12·41		9·78	91·66	433	
8·95	8·95	5·67		97·33	450	
4·47	0·85	8·10		105·43	475	
2·99	2·99	1·48		106·91	—	
6·72	5·06		2·07	104·84	510	
7·25	7·25		0·53	104·31	—	
8·36	8·36		1·11	103·20	512	
4·59	4·59	3·77		106·97	516	
6·95	5·12		0·53	106·44	520	
7·28	7·28		0·33	106·11	540	
7·60	7·60		0·32	105·79	560	
7·80	7·80		0·20	105·59	580	
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134·75	147·59	19·02	31·86			

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with the level in any single position being entered as fore-sights.

LEVEL BOOK No. 3

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4·47	0·85×	8·10		105·43	475	
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6·72	5·06×		2·07	104·84	510	
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	8·36		1·11	103·20	512	
	4·59	3·77		106·97	516	
6·95	5·12×		0·53	106·44	520	
	7·28		0·33	106·11	540	
	7·60		0·32	105·79	560	
	7·80		0·20	105·59	580	
	8·29×		0·49	105·10	600	
52·37	65·21	19·02	31·86			

Intermediate-Sight.—In form No. 4 all readings between the first and last sights before changing the position of the instrument are entered as intermediate-sights.

Back-Sight.—The first sight read off the level staff is booked in forms Nos. 2, 3, and 4, as a back-sight, and gives, as shown in form No. 1, the height of the line of collimation in the instrument, above the point upon which the level staff is placed.

—— LEVEL BOOK —— N° 4

BACK SIGHT	INTERMEDIATE	FORE SIGHT	RISE	FALL	REDUCED LEVELS	LENGTHS	REMARKS
3·71					117·94	BM	
	5·06			1·35	116·59	0	
9·40		7·88		2·82	113·77	200	
	10·20			0·80	112·97	375	
	12·30			2·10	110·87	400	
3·87		13·89		1·59	109·28	414	
2·63		11·71		7·84	101·44	426	
14·62		12·41		9·78	91·66	433	
	8·95		5·67		97·33	450	
4·47		0·85	8·10		105·43	475	
	2·99		1·48		106·91	——	
6·72		5·06		2·07	104·84	510	
	7·25			0·53	104·31	——	
	8·36			1·11	103·20	512	
	4·59		3·77		106·97	516	
6·95		5·12		0·53	106·44	520	
	7·28			0·33	106·11	540	
	7·60			0·32	105·79	560	
	7·80			0·20	105·59	580	
		8·29		0·49	105·10	600	
52·37		65·21	19·02	31·86			

Fore-Sight.—In forms Nos. 2 and 3, all sights read off the level staff after the back-sight, and in form No. 4 the last sight or reading read off the level staff before changing the position of the instrument, are booked as fore-sights.

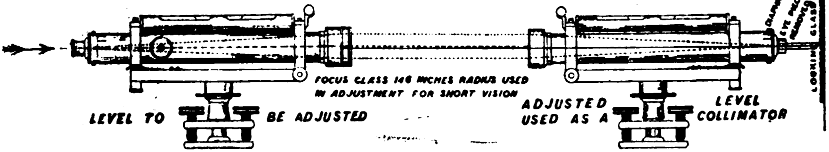
Horizontal distances are localised by description in the column headed Remarks.

The reading of each intermediate and fore-sight gives the vertical distance between the line of collimation, found as above, and the points upon which the level staff is held. The next back-sight is booked in its own column upon the same line as the last fore-sight, in forms Nos. 2, 3, and 4, because the description of that point is the same, the level staff being replaced upon the same point as that upon which the last fore-sight is taken, for ascertaining the figures to be booked, when reading the next back-sight, with the instrument in a new position. In continuous levelling great attention must be paid to this. In form No. 1 the column headed Distances and Staff are entered in the field. The columns headed Reduced Levels and Line of Collimation are subsequently arrived at by addition and subtraction. In forms Nos. 2, 3, and 4, the columns headed Back-Sight, Intermediate, Fore-Sight, and Lengths, denote the entries made in the field, while the columns headed Rise, Fall, and Reduced Levels, denote the entries afterwards made in the office. To check the accuracy of the arithmetical operations, the columns of the back and fore-sights and the columns of the rises and falls should be respectively added up page by page independently. In each case the lesser sum is subtracted from the greater, and in thus proving the accuracy of the column of reduced levels in form No. 1 the first sights and last sights are each distinguished at the side by a special mark, and then separately added up. In form No. 2, where no intermediate column is introduced, the back-sight being the height of the level of the line of sight above the point upon which the level staff was last held, a back-sight must for purposes of reduction be written in the back-sight column, so that the previous fore-sight is written as a back-sight, unless the instrument has changed its position. In form No. 3 these sights are treated in the reduction as back-sights, as well as fore-sights, without being re-written in the back-sight column. In form No. 4 they are written in a separate column, and headed as *inter-*

mediate-sights, there being no occasion to add the same figures to both sides as in form No. 2, in order to obtain the total rise or fall between the first and last reduced level.

Adjustment for Collimation.—The line joining the optical centre of the object-glass and a point in the line of the horizontal cross-hair in the diaphragm of a level should be horizontal when the longitudinal bubble is in the centre of its run. This adjustment is effected by the capstan-headed adjustment screws at the eye end of the telescope, which serve to raise or depress the diaphragm plate. Theoretically, a re-determination of this adjustment, known as "the adjustment for collimation," should be effected whenever the object-glass is removed from the telescope; but if the object-glass be carefully screwed home, or returned as near as possible to the exact position it occupied before removal, this adjustment need not be repeated. After conveying the instrument by railway, or when carried in a cab for some distance, the collimation adjustment should be tested prior to using the instrument for taking levels. It is generally determined by the makers, with the use of an adjusted level as a "collimator." The cross-hairs of the adjusted level are placed in the principal focus of the object-glass, which, compared with the eye-piece, is of long focal length, so as to adjust for an infinite distance.

DUMPY LEVEL—DIAGRAM SHOWING METHOD ADOPTED BY THE INSTRUMENT MAKER FOR THE ADJUSTMENT OF THE LINE OF COLLIMATION IN THE LEVEL.——

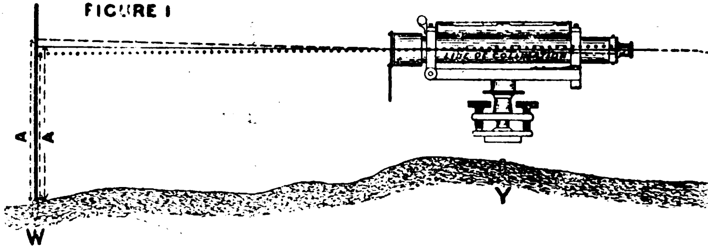

DIAPHRAGM PLATE
EYE PIECE REMOVED
LOOKING GLASS
FOCUS GLASS 148 INCHES RADIUS USED IN ADJUSTMENT FOR SHORT VISION
LEVEL TO BE ADJUSTED
ADJUSTED LEVEL USED AS A COLLIMATOR

NOTE—THE LEVEL OF THE LINE OF COLLIMATION NEED NOT NECESSARILY BE EXACTLY THE SAME IN THE TWO INSTRUMENTS IN ORDER TO MAKE THE ADJUSTMENT.—(SEE DOTTED AND FULL LINES ABOVE)

The instrument is set up level, and the eye-piece removed from its socket. As a temporary protection for the cross-hairs, a piece of plain glass may be inserted. The shade covers are also taken off each telescope. It will be seen from the diagram (page 82) that when the instrument to be adjusted

DUMPY LEVEL ADJUSTED FOR C

FIGURE 1



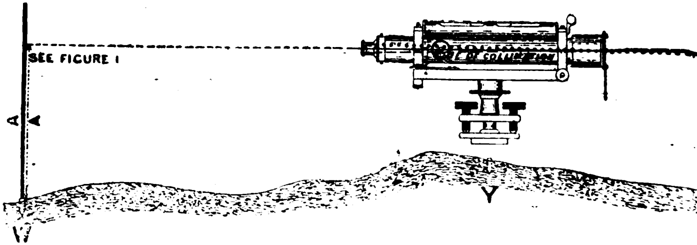
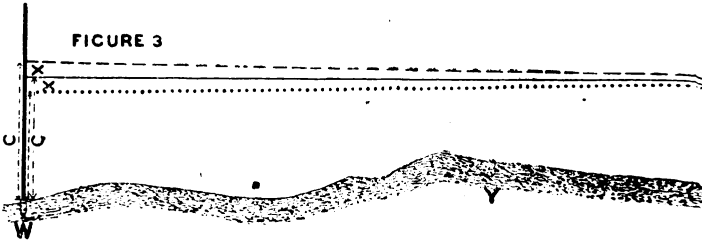
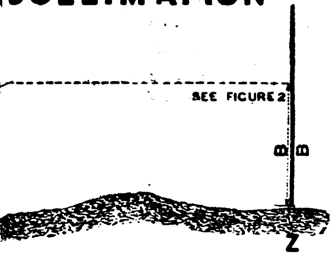


FIGURE 3



[*Field Work and Instruments, pp.* 186, 187.

COLLIMATION



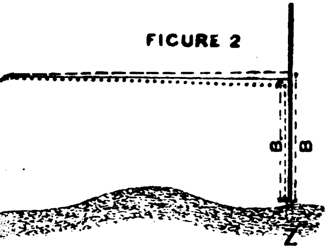
HORIZONTAL MEASUREMENT

$$WY = YZ$$

—FIGURES 1&2—

$$A - {}'B = A - B$$

FIGURE 2



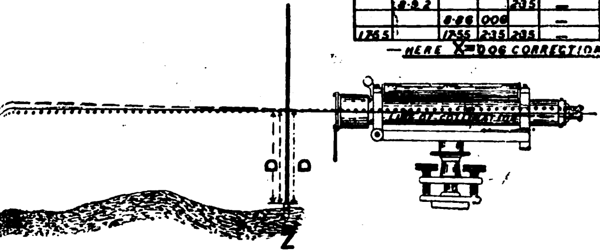
—FIGURE 3—

$$\left.\begin{array}{l} C = A - B + D \\ C = C \pm X \\ C = A - B + D \end{array}\right\}$$

—EXAMPLE—

BACK-SIGHT	INTERME-DIATE	FORE SIGHT	RISE	FALL	REDUCED LEVELS	LENGTHS	
10·88					—	A	W
		8·66	2·22		—	B	Z
6·67					—	D	
	8·92			2·35	—	C	W
		8·86	0·06		—	C	
17·55		17·55	2·35	2·35	—		

—HERE X=·006 CORRECTION—



is set level, a pencil of rays, proceeding from a point in the plane of the horizontal cross-hair of the diaphragm of the collimator, will, after passing through the object-glass, run parallel, and should the axis of the pencil be horizontal, the parallel rays between the two levels will be also horizontal. The parallel rays, after emergence from a special level, when used as a collimator, falling upon the object-glass of the level to be adjusted, will be converged to a point within the telescope, and an image of the wires or cross-hairs of the collimator will be formed. The horizontal cross-hair of the level under adjustment should then be made to coincide with the image of the horizontal cross-hair from the adjusted level, which is used as the "collimator," by loosening one of the collimation adjustment screws in the instrument to be adjusted, and tightening the other, care being taken to observe that the longitudinal bubbles in both instruments remain in the centre of their run while the adjustment is being made. As indicated by the diagram (page 188), a little difference in the height of the two instruments will not affect the result, but it is desirable to reduce this difference of level to a minimum. The level is adjusted by the makers for both short as well as long vision. For short vision, a focus-glass of a calculated radius is placed over the object-glass of the level to be adjusted.

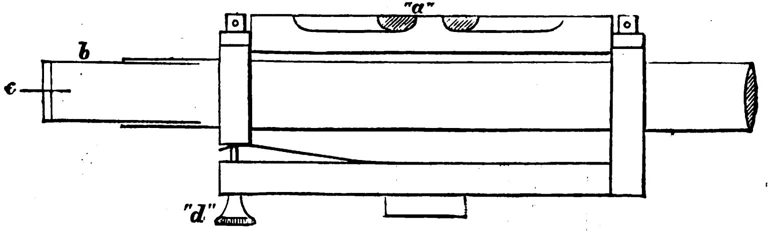
A ready means of adjusting the fixed telescope of a dumpy level for collimation, without the aid of a collimator, is illustrated by figs. 1, 2, 3 (pages 186, 187). Three pegs are driven into the ground as far apart as practicable, and at equal distances, say 4½ chains, or about 300 ft. apart. Place the instrument over the centre peg marked Y, and having set the bubble level, read the staff on the peg W (fig. 1). Then turn the telescope horizontally half-round, carefully re-set the bubble, if necessary, and read the staff on the peg Z (fig. 2). It will be evident that the correct difference of level between the points W and Z can be thus obtained, because if the reading of the staff A be above or below the true line of collimation, as indicated by the dotted lines in the diagram (fig. 1), the error at the same distance from the instrument will be the same in the case of the staff B (fig. 2). Having determined the true difference of level between the points W and Z by figs. 1 and 2, set up the level near to the highest of these points in line with both points W and Z, but not between them (fig. 3). Adjust the longitudinal bubble to the centre of its run, and read the staff first upon the point Z, and next upon the point W. The difference of level should then be the same as previously determined. If any discrepancy exists, calculate from the amounts arrived at by figs. 1 and 2 what the staff C, over the point W, in fig. 3 should read, and by means of the collimating screws, adjust the horizontal cross-hair until this reading upon the staff C is obtained. The distance between the instrument and the staff D in fig. 3 should be only just sufficient to clearly read the divisions upon the staff through the telescope, in order that any divergence of the line of collimation from the true level may have an inappreciable effect upon the height read on the staff D. Thus if in fig. 1 the staff reads 10·98 and in fig. 2 it reads 8·69, the true difference of level between the top of the pegs marked W and Z will be 2·29, that is to say, the top of the peg Z will be 2·29 ft. above the top of the peg W. Then with the level in the new position shown in fig. 3, if the staff reads 6·57 upon this peg Z, it should read 8·86 upon the peg W in order to give the same difference of level as in figs. 1 and 2, but as it reads 8·92 it shows that the line of collimation is 0·06 ft. above the horizontal line at the distance indicated by the diagram—and the correction must be made accordingly.

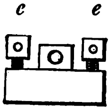
Troughton and Simms's Level.—When the bubble "*a*" is in the centre of its run the direction of the movement of the draw *b* should be horizontal. Consequently, there can be but one position for this level, which, having been determined by the maker of the instrument, may be regarded as constant. The insertion of a new level will alone disturb the relation which exists between the level and the telescope; in such a case a re-determination of its position will be necessary. The screws *e e* (see diagram, page 191) are supplied for the purpose of bringing the bubble into the level position indicated. Unless the level be broken they should not be touched, and after the new level has been inserted, if once adjusted, no similar correction will subsequently be needed.

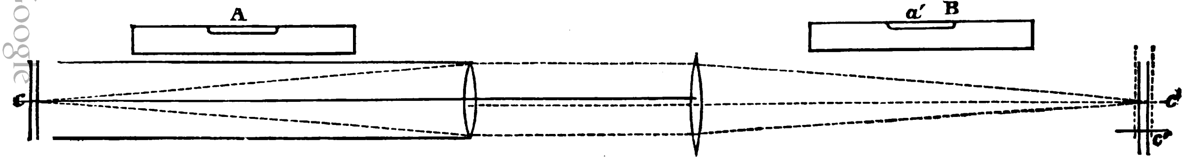
It is necessary to keep the instrument in such order that the line joining the optical centre of the object-glass and a point in the line of the horizontal wire should remain horizontal when the bubble "*a*" is in the centre of its opening, but whenever the object-glass has been removed, a re-determination of this adjustment, known as the adjustment of the line of collimation, will be required.

The horizontality of the line of collimation should be maintained during a complete revolution of the instrument upon its axis. In order to effect this adjustment the bubble "*a*" is brought into the centre by means of the parallel plate screws. The telescope is then turned 180° upon its vertical axis, should the position of the bubble have changed, half the difference between this new place and its old position has to be effected by the parallel plate screws, and the remaining half by the screw "*d*" which is placed inside cap under the stage, and which raises or lowers the spring (page 191), supporting the end of the telescope near the eye-piece. This adjustment is known as the adjustment for reversion; it is comparatively of secondary importance, and can be accomplished at any time in a few seconds. An adjusted level (used as a collimator) will supply a ready means for the accurate adjustment of other instruments. In order to effect this purpose, the wires must be placed in the principal focus of the object-glass, the eye-piece should be removed from its socket, and, as a temporary protection for the webs, a piece of plain glass may be inserted. The level should now be erected, and the bubble brought accurately into the centre (see diagram, page 191).

Let A be the adjusted level; B the instrument, the adjustment of which is to be checked; a pencil of rays proceeding from a point in the plane of the horizontal wire (*c*) will, after passing through the object-glass, be parallel, and, should the axis of the pencil be horizontal, the parallel rays will, after emergence, be also horizontal. It will be perfectly clear that if the level A be in adjustment, and the bubble "*a*" in the centre of its opening, the horizontality of this parallel pencil is ensured.


"a"
b
c
"d"


c
e

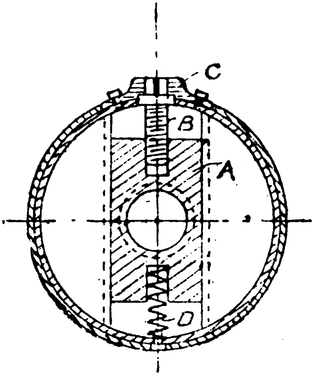

A
a′
B
c
c
c′

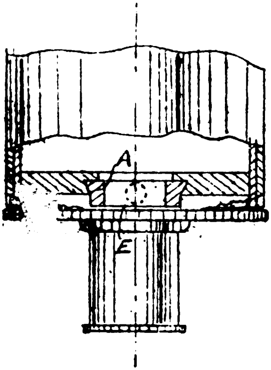
The level under adjustment (B) is to be placed with its object-glass in front of the object-glass of (A). The parallel rays from A falling upon the object-glass of B will be converged to a point within the telescope, and an image (c') of the wires (c) will be formed.

If the bubble (a') of the level B be brought into the centre by the parallel plate screws, and the level B be in adjustment, the wires in B will lie upon the image of the wires in A. Should this not be the case, let them occupy a position as (c''); the operator will now have to release the lower collimation screw and to tighten the upper, thereby raising the wire frame until he has brought c'' upon c'; when this has been done (provided the bubbles in both instruments retain their central position) the adjustment for collimation has been accomplished.

The attachment at *d* is secured by a lock nut which is placed above the connecting stage.

Brightmore's Collimation Adjustment.—This contrivance consists of a sliding-plate, A, on the face, E, of which the cross-hairs are stretched (see page 193). It is caused to move in a groove in the diaphragm by a screw, B, pressed against its support, C, by means of a spring, D. The advantages claimed over the ordinary method of adjustment are that:—1. The uncertainty in adjusting, inseparable from the usual two-screw method, is entirely avoided; 2. In adjusting an instrument fitted with this improvement, the movement of the cross-hair is exactly proportional to the turn of the screw; 3. The cross-hair can be adjusted without disturbing the horizontality of the spirit level, which allows the exact correction required to be made at once without several trials; 4. The time required to put an instrument in adjustment is very much shortened; 5. As it is impossible to strip the thread off the screw, as often happens with the ordinary two-screw arrangement, there is no tendency for the instrument to shake out of adjustment when moved about; 6. The frequency that adjustment is required is considerably reduced; 7. By this method the adjustment of the cross-hairs, instead of being the result of trial and error, becomes, as it should be, the most accurate in the instrument, having all the certainty and exactitude of a fine tangent screw adjustment; 8. It is not necessary to carry about any special pin for adjusting, the point of the blade of a penknife being all that is necessary. The cost of fitting to an existing level is 10s. 6d., and if provided to a new level, extra, 5s. It can also be fitted to theodolites for adjusting in one or two directions at right angles.





Stevenson's Level.—Figs. 1 and 2 of the annexed illustration (page 196) show a levelling instrument invented by the late Mr. David Stevenson, M.Inst.C.E, in 1844. It consists of a 10-in. telescope, arranged to unscrew at A, so as to pack conveniently in two parts. B C represents the longitudinal level, D a circular, or, more correctly speaking, a spherical level, E a compass, F the screw for adjusting the focus when viewing an object, and G the eye-piece. The telescope rests in a support marked M, which is attached to the body

DOERING'S GIMBAL

FIGURE I

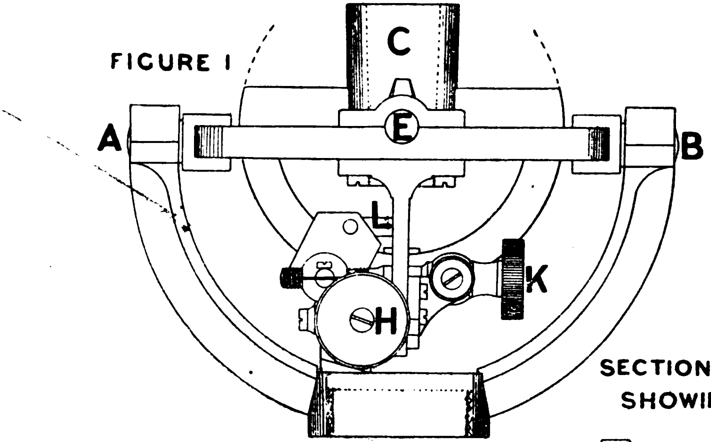
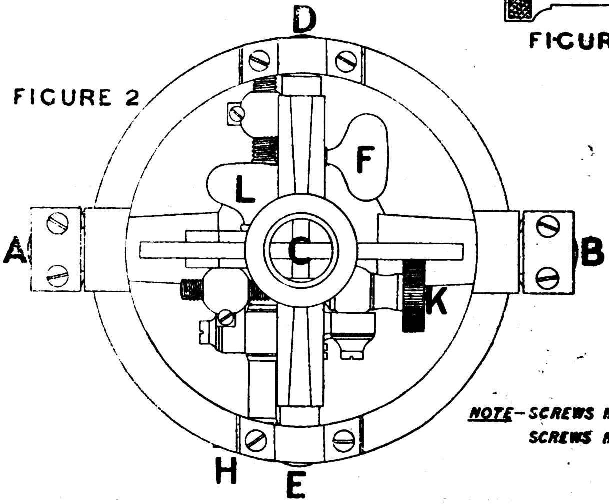


FIGURE 2



SECTIONAL P
SHOWING C

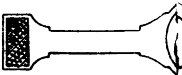


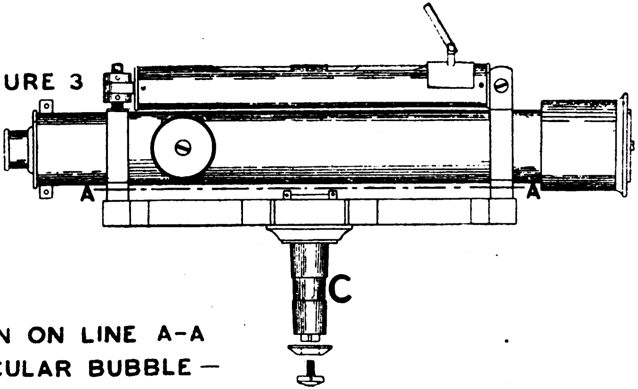
FIGURE 4

NOTE—SCREWS MARKED
SCREWS MARKE

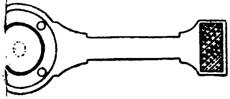
[*Field Work and Instruments*, *pp.* 194, 195.

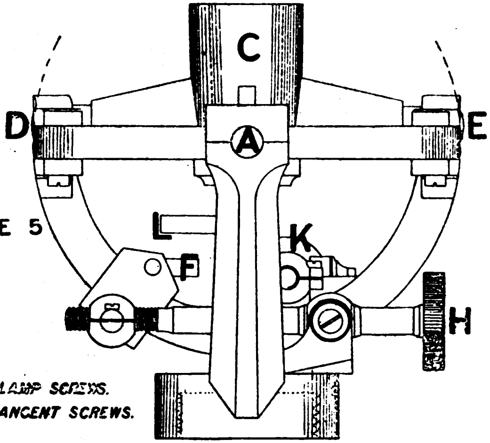
OINT TRIPOD HEAD

CURE 3



AN ON LINE A–A
CULAR BUBBLE —





FICURE 5

L ARE CLAMP SCREWS.
K ARE TANCENT SCREWS.

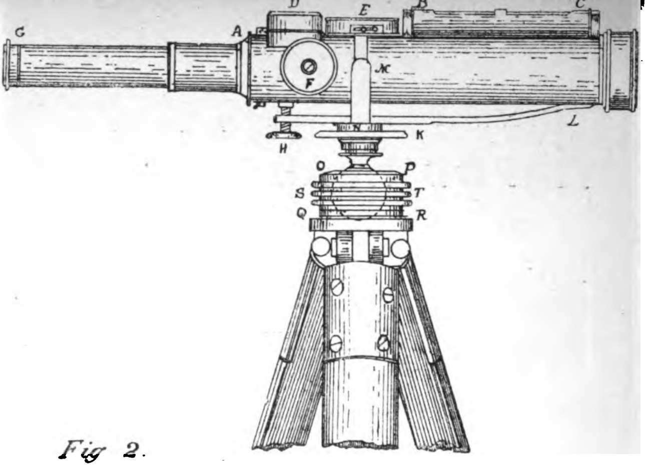


Fig 2.

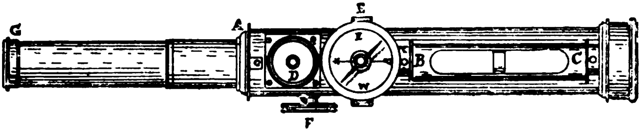
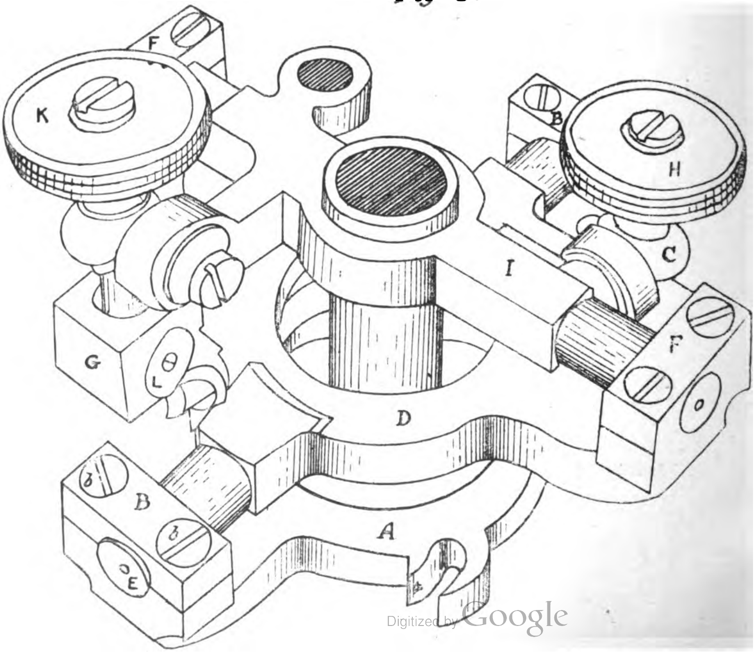


Fig. 3.



of the instrument by a screw at N, and is secured to the tripod by a ball-and-socket joint, indicated by dotted lines in fig. 1. This joint is constructed to be clamped and unclamped by means of a screw, worked upon the inner circle of the piece marked S T. The telescope is balanced at M by the spring K L, and is acted upon by the elevating screw marked H. To set the instrument level, the screw-plate S T is first unclamped and the telescope is carefully moved by the hand until the circular bubble at D appears central. The screw-plate S T is then moved by the hand so as to clamp the ball-and-socket joint, and the telescope being directed to the point of observation required, the final adjustment is effected by setting the longitudinal bubble B C in the centre of its run by turning the milled head of the screw H. It will be observed that in this instrument, no preliminary setting of the level by the tripod legs is required, but that any movement of the telescope would necessitate the longitudinal bubble requiring to be re-adjusted to the centre of its run, in order to make the line of collimation horizontal (see page 196).

Sang's Level.—One of the earliest forms of gimbal action employed to aid the setting-up of a level is shown in fig. 3 (page 196), which illustrates the arrangement contrived by the late Mr. John Sang, of Kirkcaldy, in Fifeshire. The lower portion, marked A, is secured to the head of the tripod, and the vertical axis of the telescope is supported in the central socket, which is connected by a horizontal axis, marked I, to the socket-bearing at F F. These bearings are rigidly attached to the middle piece, marked D, which has an axis, E, working in the sockets B B. The axis B B is at right angles to the axis F F, and the trunnions of these two axes are formed by a double cone fitted into the socket-bearing and clamped by screws, marked *b b*. The milled-headed screws, marked K and H, work each in a nut, which by a revolving-joint are connected in each case to a crank arm, so that by their means the upper portion, marked I, is adjusted in one direction, and the central portion, marked D, is adjusted in the other direction, as required.

Doering's Level.—Another form of gimbal-joint action

PASTORELLI

FIGURE 1

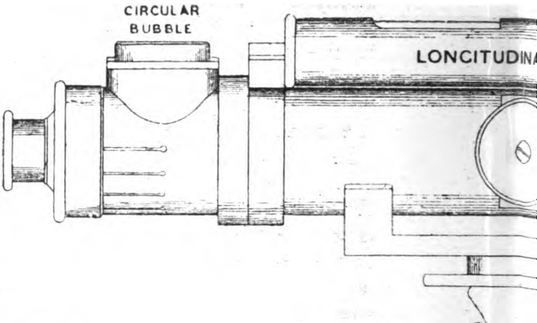
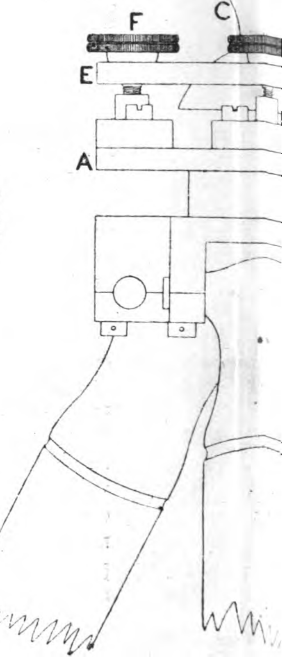
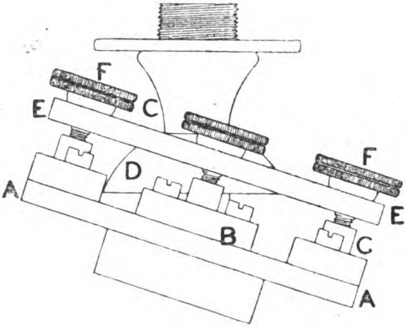



FIGURE 2



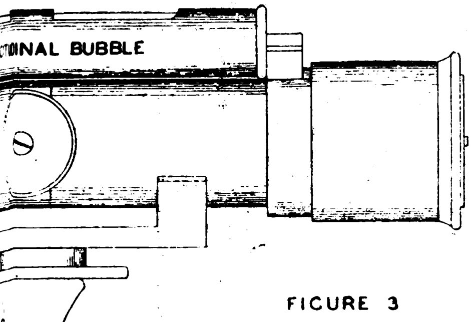
A—*LOWER PARALLEL PLATE SCREWED ON STAFF HEAD. THE STAFF HEAD IS THE ADOPTION OF A PLAN BY THE LATE MR W FROUDE.*

B—*BALL-JOINT IN CENTRE OF PLATE* A, *WHICH ALLOWS THE INSTRUMENT TO MOVE NEARLY 20° OF INCLINATION, SO THAT THE TRIPOD MAY BE SET UPON THE GROUND ALMOST IRRESPECTIVE OF THE POSITION OF THE LEVEL.*

C—*VERTICAL AXIS WITH SOCKET END RESTING ON BALL* B, *AND CARRYING INVERTED CUP AND INSTRUMENT*

D—*INVERTED CUP ATTACHED TO VERTICAL AXIS* C, *FOR RETAINING THE INSTRUMENT IN POSITION.*

I'S LEVEL



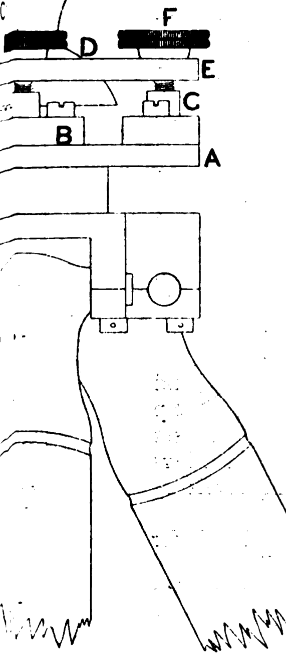
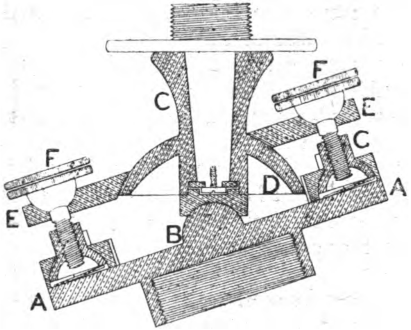


FIGURE 3



E — UPPER PARALLEL PLATE, CARRYING ADJUSTING SCREWS. THE HEADS OF WHICH WORK IN SOCKETS FORMED IN PLATE.

F.F — THE ADJUSTING SCREWS FOR CLAMPING CUP D AND FINALLY ADJUSTING THE LEVEL.

C — MOVEABLE NUTS WITH BALL AND SOCKET ENDS.

NOTE: THE CUP D IS CONCENTRIC WITH THE BALL JOINT B, AND THIS AND THE BALL AND SOCKETS OF THE NUTS C ARE IN THE SAME GEOMETRICAL PLANE.

in a tripod head is that shown in figs. 1, 2, and 5, illustrating Doering's level (pages 194, 195). This method of supporting a levelling telescope is similar to the system adopted for a ship's compass, with the addition of vertical arcs at right-angles to one another respectively, which are clamped to each other by the thumb screw marked L, and by the thumb-screw marked F to the frame, which is fastened upon an ordinary tripod stand. In the field when setting up the instrument, should the ground be very uneven, the legs of the tripod can be put down anywhere in the most convenient manner, irrespective of level, and the telescope afterwards adjusted by moving the vertical arcs which connect it with the tripod stand. Fig. 3 illustrates the telescope, the vertical axis of which is connected at C in the socket-bearing shown in elevation in figs. 1 and 5. As shown in fig. 4, a central circular bubble is substituted for the ordinary transverse bubble. Figs. 3 and 4 are here drawn to half the size to which figs. 1, 2, and 5 are drawn: hence the socket-bearing marked C in figs. 1, 2, and 5 appears double the diameter indicated by figs. 3 and 4. Fig. 2 shows in plan the relative positions of the elevations illustrated by figs. 1 and 5.

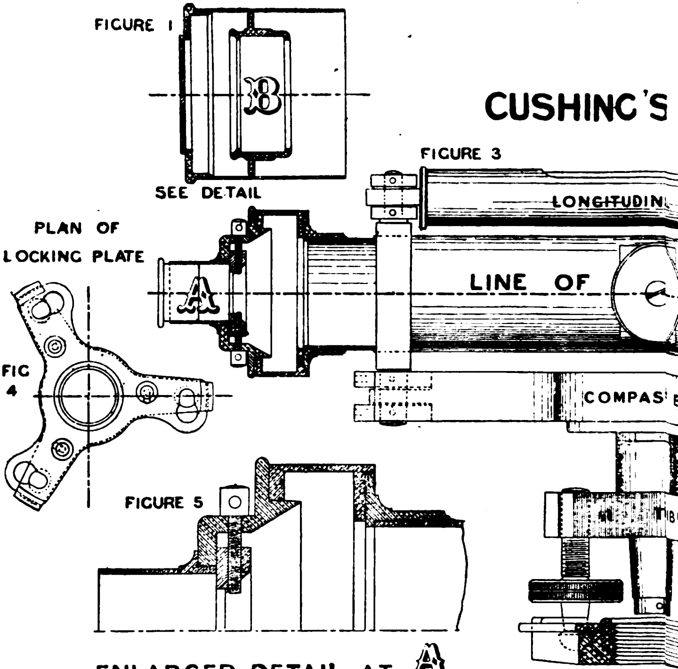
In setting up the instrument upon irregular ground, the clamps marked F and L which hold the telescope rigidly to the tripod stand are first slackened and the longitudinal bubble is set approximately level by hand. The clamps F and L are then tightened and the final adjustment made by the two milled-headed tangent screws marked H and K working in directions at right angles to one another. These screws are connected respectively to each arc at the clamps, as shown in figs. 1 and 5. Should the ground be moderately level and firm, it is unnecessary to unclamp the vertical axis of the joint. The instrument is first set up approximately level in the ordinary manner by the legs and brought to a perfect adjustment for taking levels by means of the tangent screws.

The substitution of the gimbal joint tripod head for parallel plates enables the telescope to be rapidly set level in rough country, but it has a greater area exposed to the action of the wind, and more wearing surfaces. In adjusting the telescope by the gimbal joint, after fixing the legs firmly in the ground, the telescope should be held round the body beneath the compass-box, before the clamps are slackened. One of the arcs may be divided into degrees for measuring vertical angles, if desired.

Pastorelli's Level.—In Pastorelli's instrument, the horizontal bar to which the telescope is attached is either made shorter than in other patterns, or is dispensed with altogether. In the latter case, the telescope is soldered to a saddle-piece, the base of which is made parallel to the axis of the telescope, and the saddle-piece is also rigidly fitted to the gun-metal stem or pivot, which connects it with the joint at the parallel plates. In the former case, as shown in fig. 1, the telescope can be detached at the screw connexion indicated in figs. 2 and 3 (pages 198-9). By a comparison of the elevation shown in fig. 2 and of the section shown in fig. 3 with the general elevation given in fig. 1, it will be seen that the vertical axis of the instrument, marked C, terminates in a socket which rests upon a gun-metal ball formed over the centre of the lower parallel plate. This is marked B in the illustration, and the construction permits the instrument to traverse vertically about 20° of inclination from the perpendicular. The underneath of the vertical axis is formed in an inverted cup shape, the curve radiating from the centre of the ball-joint. The lower parallel plate, marked A, is screwed on to a special form of tripod head, originally suggested by the late Mr. W. Froude, The three pairs of cheeks, to which the legs are here attached, are set wider apart than in the ordinary systems, and arrangements are provided for tightening the trunnions in their connexion at the cheeks, by bisecting the cylindrical bearings in which the leg-joints work, and fastening them together by means of the capstan-headed screws indicated in fig. 1. This improvement conduces to increased steadiness and freedom from vibration as wear goes on, so far as the tripod head is concerned. The wooden legs sometimes are each circular in section, and when closed up for conveying from one station to another are very uncomfortable to carry.

The level is retained in position by the upper parallel plate marked E, which encircles the inverted cup marked D,

CUSHING'S

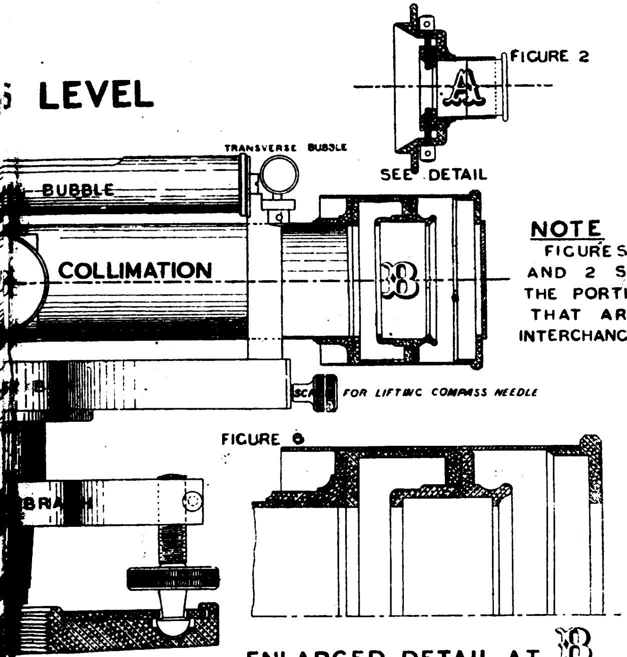


ENLARGED DETAIL AT A

NOTE — THE DIAPHRAGM WIT
AT EITHER END INTERCH
GLASS FOR THE PURP
COLLIMATION — SEE D

[*Field Work and Instruments, pp.* 202, 203.

LEVEL



NOTE

FIGURES 1 AND 2 SHOW THE PORTIONS THAT ARE INTERCHANGEABLE

ENLARGED DETAIL AT B

THE EYEPIECE CAN BE ATTACHED
NCEABLY WITH THE OBJECT
E OF ADJUSTMENT FOR
AILS ———

and is clamped by the milled-headed adjustment screws marked F F. The cup-piece, D, is concentric with the ball-joint, B. The parallel plate adjustment screws each have spherical projections formed under their heads, which projections work in corresponding sockets formed in the top side of the upper parallel plate. These screws work in movable hemispherical nuts marked G, which themselves are held in seats, as shown attached to the lower parallel plate. By tightening or slackening these screws, the upper parallel plate is made to clamp or to release the inverted cup attached to the vertical axis of the instrument. By loosening any two adjacent screws, F F, the telescope can be tilted over by hand in the required direction, until the longitudinal bubble is approximately in the centre of its run, final adjustment being effected, after tightening the adjacent screws previously slackened, by turning the opposite parallel plate screws in the usual way.. The tripod may be set upon the ground almost irrespective of level, and the telescope thus accutately set level without straining the parallel plates. Unlike the above arrangements, the ordinary parallel plates are very limited in their action, compelling the tripod-head to be placed within a small deviation from a horizontal plane, whereas the combination of the movable ball-joint with the parallel plate clamp enables this form of tripod to prove of great value for work over very uneven country. It will be observed, however, that in this instrument the telescope stands higher than in ordinary instruments, and that, consequently, the vertical axis is longer. Before carrying the instrument from one station to another, care must be taken to tighten the plate-screws sufficiently to prevent the telescope from falling over in its vertical axis bearing. It will be further noticed that around the telescope are soldered two cylindrical gun-metal collars, very accurately turned and fitted to a perfect circumference. The longitudinal bubble, being fastened to these collars, can be fitted and framed parallel to the mechanical and optical axis of the telescope, with which the line of collimation should be coincident. The centres of the movable nuts of the plate-screws are placed by the makers in the same geometrical plane as the centre of the ball-joint at the foot of the vertical axis, thus insuring the most perfect action in the motion of the upper parallel plate.

The diaphragms in Mr. Pastorelli's instruments were originally arranged in two separate discs, the horizontal web being mounted in one, and the cross webs in the other. These discs could be moved independently of one another by means of special collimating screws so arranged that when set, they cannot be disturbed, a grooved channel being formed in the eye-piece of the telescope, into which the collimating screws are sunk. After the collimation was perfected, a cylindrical ring cap was placed over these screws and made fast, thus keeping intact one of the most important adjustments of the instrument. It was, however, found that the adjustment of the double diaphragm proved more tedious than the ordinary kind, and hence the maker now applies only the single diaphragm, unless the double form be specially ordered (see pages 198, 199).

Cushing's Level.—In Cushing's level the object-glass and the eye-piece are constructed to be interchangeable for either testing or adjusting the horizontality of the line of collimation. Figs. 1 and 2 (pages 202-3), show the eye-piece and object-glass ends, marked A and B, removed from the telecope. A gun-metal socket is fixed, as shown in section in fig. 3, upon one end of the inner brass tube and also upon the opposite end of the outer brass tube, both sockets being flanged to receive either the eye-piece or the object-glass fittings. The object-glass fitting at B is made somewhat longer than the fitting at A, because it has to carry the shade cover, but in other respects the bearing surfaces to receive either the object-glass or the eye-piece ends are identical. The eye-piece is attached to the telescope by a kind of bayonet fixing, in which it is brought to its proper position against stops, and secured to the flange of the socket by means of two screws. The object-glass end is fixed in a similar manner. The eye-piece end carries the diaphragm plate, which contains fine lines ruled upon plain and parallel glass attached to the removable eye-piece end. In the open field it would be dangerous to allow this removal unless the diaphragm was of this permanent nature. The telescope is supported by the ends of the horizontal limb containing the compass, as shown in fig. 3, the support at one end (where a means is provided for lifting the compass needle), being capable of a slight rocking motion in the direction of the axis of the telescope, while the support at the other end has a lifting or lowering arrangement for adjustment in setting the axis of the telescope at right angles to the vertical axis of the instrument. The vertical axis is fixed rigidly to the limb, and revolves in a socket made in the central boss of the upper parallel plate, being secured by a nut at its lower end. The parallel plates as shown in plan in fig. 4 are constructed upon the tribrach principle radiating from a central boss, in a socket of which the vertical axis revolves (see pages 202, 203).

Having made the longitudinal bubble reverse by means of the capstan-headed nuts attached to the screws fixed at the end opposite to the transverse bubble, the parallelism of the optical axis in the telescope to the run of the longitudinal bubble can be tested by reversing the eye and object-glass ends. If any adjustment is then needed, it is effected by means of the vertical capstan-headed nuts in the eye-piece. In thus testing the line of collimation it is of course necessary to traverse the telescope half-round, after reversing the ends A and B, so that the point in a distant object viewed with the eye-piece at one end of the telescope may be again observed with the eye-piece attached to the other end. It is important in changing the object-glass from one end to the other in this adjustment to observe that the part of the cell which has the small screw-hole in it, is kept uppermost, and that the eye-piece is reversed without turning the diaphragm plate vertically over.

Cooke's Reversible Level.—A general view is given on Plate 1, and its construction is shown on Plate 2, where fig. 1 is the telescope (shown in longitudinal section), which bears two perfectly equal cylindrical flanges F and F′ turned on it concentrically with the tube, being essentially similar to the telescope of a Y level. The cross lines, consisting of one horizontal line and two subsidiary vertical lines, are ruled upon parallel glass carried by a perforated block in the eye-end, which is adjustable vertically, to correct collimation by the two antagonist screws *d* and *d*. The object-glass is made

[*Field Work and Instruments pp.* 207, 208, 209.

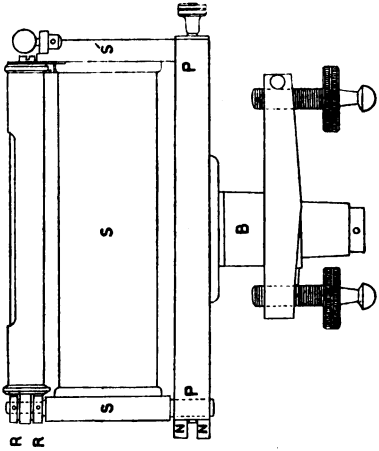


FIG. 2.

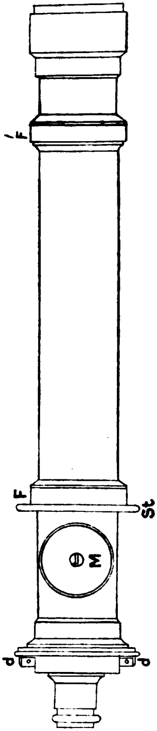


FIG. 1.

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ASTOR, LENOX AND
TILDEN FOUNDATIONS.

to approach to or recede from the cross-lines for focussing by turning the milled head M.

The two flanges F and F′, instead of resting upon two Y's, fit perfectly within two corresponding collars S and S′, which latter form the ends of the rigid socket SSS′. The two flanges F and F′ and their corresponding collars S and S′ being exactly equal, the telescope tube can be introduced indifferently from either end of the socket SSS′ and pushed home until the stop-flange S*t.* comes in contact with the socket end. The telescope can be further secured in its socket by the screw S*c.*

One end S of the socket is furnished with a threaded bolt which passes through a hole in the base plate PP and is adjustable vertically, and locked by the two lock-nuts N & N.

The adjustment of the socket SSS′, so that its axis of figure may be exactly at right angles to the vertical axis B, is effected thus:—

First, some minute and well-defined test object, which need not necessarily be on the same level or height as the instrument, is selected. A small needle hole in a piece of paper, fixed not less than 20 feet away, forms a convenient mark; but if the instrument requires adjustment in the open field, where perhaps the above-mentioned mark cannot be made use of, it will be most likely an easy matter to select some immovable and sufficiently well-defined test mark from the features of the surrounding landscape. The instrument is mounted firmly upon its stand in such a manner that when the telescope is directed towards the test mark, it may then lie directly over one of the foot-screws. The eye-piece is carefully pushed in or out in its tube until the cross lines are seen as distinctly as possible, and the telescope is then focussed upon the test mark, and with the aid of the foot-screw, the image of the latter caused to fall nicely upon that part of the horizontal line lying midway between the two vertical lines. All error of parallax must now be corrected.

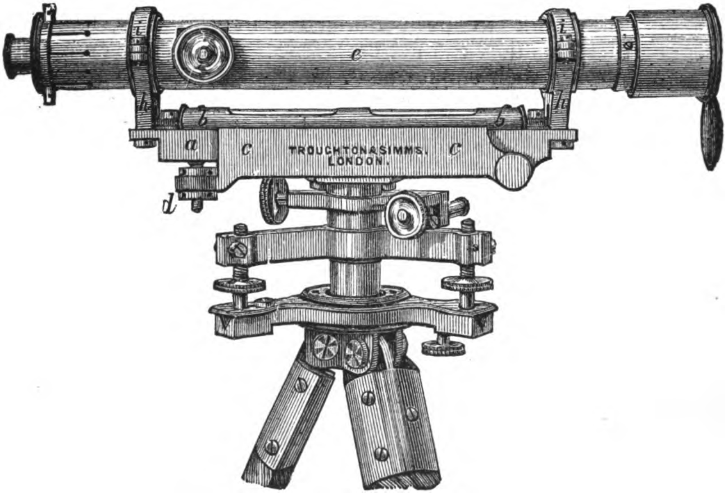
If, on redirecting the telescope towards the test object, the image of the latter is no longer bisected by the cross line, but falls either above or below it, then the foot-screw below the telescope is turned until the image of the test mark is brought as exactly as possible half-way back towards bisection by the cross line. The lock nuts N and N are then loosened sufficiently to allow them to be turned by a moderate pressure on the end of the lever used for their adjustment, and the end S of the socket is raised or lowered until the test mark is again nicely bisected by the cross lines, after which the operations of reversal of the telescope in its socket, and the correction of the error, half, by the foot-screw; and half, by the lock nuts N and N are repeated, until the bisection of the image is as nice and exact as possible, and remains quite undisturbed by the reversal of the telescope within its socket.

If it be thought necessary to adjust or examine the collimation of the telescope, the test mark is carefully bisected by the cross line, and then the screw S*c.* is withdrawn and the telescope is carefully twisted or rotated half-way round in its socket, so that the screw hole through which S*c.* passes is brought to the top, and the cross line is again horizontal. If the image is not now bisected but falls above or below the cross line, the error or deviation is half corrected by means of the foot screw lying under the telescope, and then the image is caused to be bisected by the cross line by adjusting the latter by means of the antagonist screws *d* and *d*. The telescope is twisted half-way round again and any remaining error corrected as before; if necessary, the operation is repeated until accuracy is obtained (see pages 207-209).

The Charlton Model Level.—This instrument, made by Messrs. Troughton and Simms, consists of a stage *a*, whose surface may be made truly horizontal by means of the bubble *b*. The bubble *b* is adjusted by reversion on the stage, and then finally screwed down. When in the centre of its run it indicates that the surface of *a* is horizontal. The bubble *b* is further adjusted to maintain its central position upon rotation of the axis by means of the nuts *d*, which move it relatively to the lower stage *c*. The telescope *e* is furnished with cylindrical collars equal to each other in diameter; it can be rotated in its bearings *h*, and can be turned end for end in these bearings, as in an ordinary

Y level. The bearings *h* are constructed so that when the telescope is collimated the optical axis shall be parallel to the stage, therefore (when the bubble is in the centre of its run) level. When adjusted, the screws *i* which hold the collars in the bearings are tightened; the telescope thus becomes united to its supports, and stability is obtained without losing the advantage of the ease attached to the adjustment of the Y level.

To adjust for collimation, release one of the capstan headed screws on each bearing, then setting the telescope on a mark, bisect it with the horizontal wire, now rotate the telescope in the supports, and if the mark be not bisected move the wire half the distance by the collimation, and the remaining half by the parallel plate or tripod screws. The telescope is collimated when upon rotation in its bearings the horizontal wire cuts the same mark. Now tighten the collars and adjust for reversion by the nut *d*.



The bubble *b* is not to be touched, as it is supposed to be fixed in position by the maker of the instrument.

Various contrivances have been at different times designed and constructed for the purpose of describing a section of any surface of ground traversed by a levelling instrument, or instrument which would record the undulatory character of the ground, and at the same time register the distance passed over. "The Transactions of the Society of Arts," volume xliv., page 123, describe one such contrivance designed by Mr. George Edwards, of Lowestoft; and "The Minutes of Proceedings of the Institution of Civil Engineers," volume lxi. (Session 1879-80), describe the Temnograph of Mr. A. M. Rymer-Jones. The use of such instruments, however, must from the nature of the work to be performed be of a very limited character, as they can not cross fences, and require an open country for their employment.

CHAPTER XVII.

TELEMETRY IN LAND SURVEYING.

TELEMETRY, or the optical measurement of distances, is apparently a simple matter, and might be more adopted by surveyors if it were better known. When the distances are numerous and long, and the offsets few, there are numberless cases where, particularly in the open country, instruments for telemetry, such as Porro's telemeter and Eckhold's omnimeter, are suitable for general work.

Ordinary levels, in addition to the single horizontal wire, contain two vertical wires to assist the surveyor in keeping the staff vertical; on looking through the telescope the sides of the staff are seen sometimes to coincide with the wires, and at other times to be much narrower. If the telescope could revolve upon its axis so as to bring the double wires horizontal, they would at times appear a foot or more apart, and again only a few tenths of a foot, according to the distance, but always in strict proportion to the distance. All we require, then, to convert an ordinary telescope, whether independent or connected with a level or theodolite, into a telemeter, is to fix two additional wires upon the diaphragm in such a position that when the staff is 100 ft. away they shall appear exactly a foot apart; then for 50 ft. they will appear to be separated by five-tenths of a foot, 120 ft. by one foot and two-tenths, and so on.

Upon the Continent, where the metric system is in use, this mode of measuring distances is extensively practised. The telescope is arranged with three horizontal wires, one of them central, and the others indicating a space equal to two metres upon the staff when at 100 metres distance. The staff is marked with metres and centimetres, but of double size—*i.e.*, 2 metres is marked 1 metre, 40 centimetres as 20 &c.,; then when the telescope is set level, the top reading minus the bottom reading multiplied by 100 gives the distance, and the top reading plus the bottom reading gives the level. For example, if the top reading be 1·69 and the bottom be 0·83, the distance will be (1·69—0·83) × 100=86 metres, and the level will be 1·69+0·83=2·52 metres; the middle wire reads 1·26, and this, being doubled on account of the enlarged divisions, will prove a check upon the latter figures. The extra wires are applied to the theodolite in preference to the level, so that, by one operation of setting up, the horizontal angle, distance, and level can be obtained.

Telemeter surveys differ from chain surveys in that the distances within a range convenient to the telemeter employed are obtained by observation with the instrument, instead of measurement by the chain.

Adie's telemeter is worked by taking simultaneous observations with two telescopes from the extremities of a fixed base, both of these being directed to the object whose distance is to be measured, and using the angle formed by them as the measure of the distance. Instrumental power is given by the telescopes; the rays are diverted by total reflection, so as to work into one eye-piece, and the angle subtended, is accurately indicated on the scale and vernier, which angle at once becomes a measure of the distance of the object; this arrangement also gives the instrument its convenient shape, that of a tube. The focus of both telescopes is adjusted at the same time by twisting the eye-piece.

The telemeter may be held in the hand, or with any steadying rest, or provided with a tripod stand, as steadiness gives greater accuracy.

A distinct, and generally, when obtainable, a nearly vertical well defined line, or side of any object whose distance is sought—a flag-staff, mast, corner of a house, man or like object, should be selected, holding always the line of the instrument at right angles to the longest straight line of such object. The eye is then applied first to the small tube or finder, on the upper side of the instrument, which assists in finding the object, then removed to the eye-piece, the tangent screw must be turned until the parts of the aforesaid object or line seen above and below the horizontal separation of the two telescopes are made to agree very exactly in one, forming a continuous line or object, in the centre of the field.

The scale is now to be read, and opposite that angle the distance will be found on the table, repeating this for precision. Practice is needed to adjust the coincidence well and quickly, but with that the readings should agree within one vernier division. Each division on the fixed scale in the 3 ft. instrument is 2′ (minutes), and each one on the vernier 2″ (seconds), the intermediate minutes being found by the place of coincidence of the vernier scale, and if further from zero than the minute (marked 1) on the vernier, this 1′ is added. On the 18 in. instrument each scale division is 4′, and on the vernier 4″, the intermediate minutes being found as before by the place of coincidence of the vernier, and 1′, 2′ or 3′, added, the seconds in each case being those between the minute found and the coincidence.

It is well to have an object of known distance, for occasional verification of the index error, if any such exist. The edge of the moon's disc supplies one for zero, great care being taken to use the portion of the disc at right angles to the instrument only, as any want of overlapping of the images would produce a considerable apparent error, on such round objects, if pointed to the sides oblique, or parallel to the instrument. It may be here stated, that any want of overlapping of those sides of an object which are nearly parallel to the instrument, does not affect the accuracy of the measure, so long as a nearly vertical portion of an object is used, or the instrument is held at right angles to the line of object measured at the point of conjunction of the two images.

The overlapping can be perfected if wrong when it is taken out of the sunshade or outer case, as described in directions for cleaning, by very slight application of the screw-driver to the pushing or most prominent screws underneath the large, or end prisms.

By unscrewing the eye-piece, tangent screw-head, and reader-arm, the instrument can be taken out of its case to be cleaned. If the ends be taken out, also the object-glasses, the larger prisms at the object ends can then be cleaned without displacing them, afterwards re-screw the object-glasses firmly home.

The small or eye-piece prisms can only be got at by taking out the three small screws in their plates, taking the plates off, and then carefully wiping the prism, when each may be screwed home again without derangement; it, however, being very important to ascertain the index error carefully after this is done, as it is sure to alter. Cleaning should only be needed at very rare intervals.

The 18 in. instrument will read within about six inches at 100 yards, five yards at 500 or twenty at 1000, and will work up to two miles. The 3 ft. is more than double that power and accuracy, and larger sizes in proportion. Any distance may be measured in about half-a-minute, but a mean of several readings is best, where great precision is wanted.

Mr. Adie considers that it is of great consequence to prevent a strong sun shining for a long time on one side of the instrument; it should be shaded from it by means of a piece of wood, an umbrella, or screen of some kind when long exposed, and care should be taken to carry it under a shade when necessarily used in the sun; by exposing all sides alternately as nearly as possible, the effect of the sun's rays will be greatly reduced

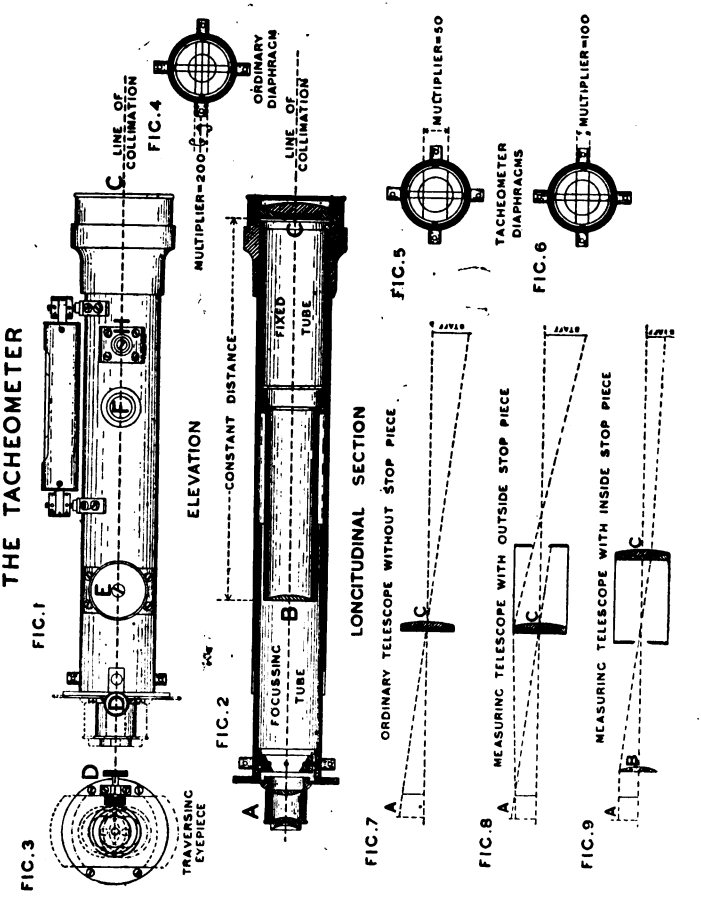
CHAPTER XVIII.

THE TACHEOMETER.

THE tacheometer (figs. 1 to 14) is an instrument designed to enable the surveyor to determine the horizontal distance of a point from the instrument by means of a vertical measurement read off a level staff (see pages 219, 220).

In a tacheometer two parallel horizontal wires are placed in the diaphragm at a given distance from each other, and at equal distances from the central horizontal cross-wire, which appears in a level. If, as in fig. 6, page 219 the distance apart of the two parallel wires from each other be one-hundredth of the focal length of the object-glass, every foot which is read upon the level staff will represent 100 ft. of horizontal distance when the instrument is set up and its telescope adjusted in a level position. In the same manner, 2 ft. read upon the staff would represent 200 ft. of distance. Figs. 1 and 2 show the special form of construction recommended for tacheometers (see page 219), but it is manifest that the diaphragm arrangement could be easily added to any levelling instrument simply by inserting two extra cross-hairs at the correct distance apart. The diaphragms in figs. 5 and 6 omit the central horizontal cross-hair used for taking levels, as shown in fig. 4. In fig. 4 the cross-hairs are fixed so as to record a horizontal distance of 200 times the height read upon the staff; fig. 5 is set to record 50 times, and fig. 6 100 times the distance. The eye-piece, as shown in fig. 3, is fitted with a slide and rack, so as to be traversed up and down to the positions shown by the dotted lines, by turning the mill-headed screw D. The diaphragm itself remains fixed. A tacheometer is almost invariably made with a three-screwed tribrach, because they are generally sold upon the Continent, where a three-screw base is preferred. In an omnimeter, an outside scale is fixed parallel to a tangent line upon the horizontal circle, the scale being finely divided for recording minute sub-divisions as shown upon page 222.

THE TACHEOMETER



ECKHOLD'S OMNIMETER

FIGURE 10

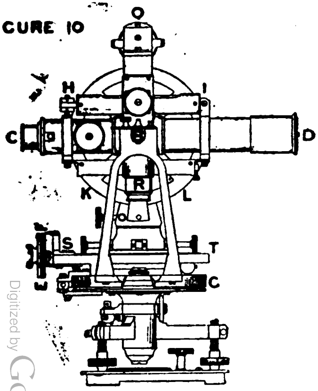


FIGURE 13

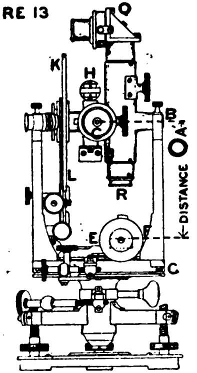
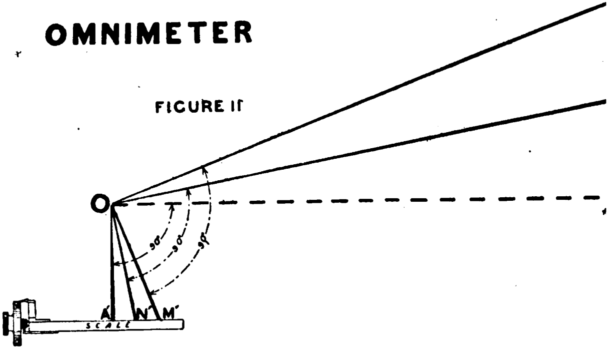


FIGURE 11



$$OA = \frac{MN \times OA'}{M'N'}$$

$$AN = \frac{MN \times A'N'}{M'N'} = \frac{A'N' \times OA}{OA'}$$

$$OA' = \frac{M'N' \times OA}{MN}$$

URE 12

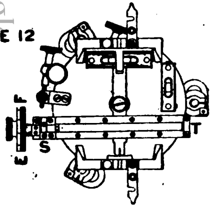


FIGURE 14

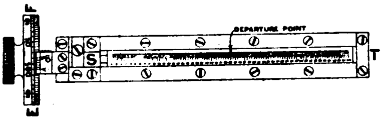


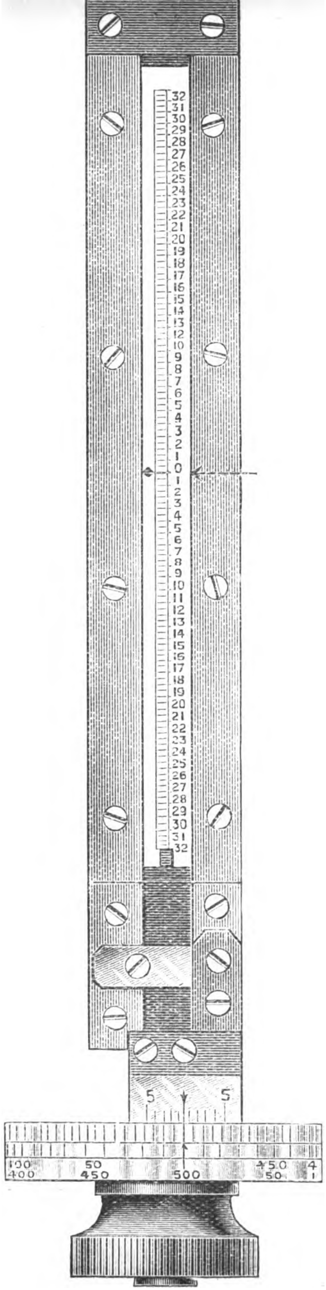
Fig. 7 (page 219) shows an ordinary telescope without a stop-piece, in which the angle between the inclined line and the horizontal has not a constant value for different relative positions of the eye-piece and the object-glass. The introduction of the stop-piece in figs. 8 and 9 serves to maintain a constant value, but by thus choosing certain rays and rejecting others, the effective power of the object-glass becomes diminished: hence the object-glass is made large in order to balance this defect by allowing more light to enter the telescope. The measurement is also calculated from the centre of the instrument in the omnimeter, which is an applied form of tacheometer (figs. 10 and 13, page 220) and has a powerful microscope Q R, permanently fixed at right angles to the telescope C D. Both microscope and telescope move upon the same axis at right angles to one another in every position. The telescope traverses as in a Transit Theodolite. When required a compass can be fixed upon the top, as shown in Adie's combined Level and Theodolite (pages 249, 250). The line through the centre of C D is always perpendicular to the line through the centre of Q R. Hence, in fig. 11, if M A represent the central portion of a level staff, the distance O A can be calculated from the readings given by the scale (fig. 14), coupled with the difference of the divisions read upon the staff (fig. 11), thus :—

$$O\,A = \frac{M\,N \times O\,A^1}{M^1\,N^1}$$

$$A\,N = \frac{M\,N \times A^1\,N^1}{M^1\,N^1} = \frac{A^1\,N^1 \times O\,A}{O\,A^1}$$

$$O\,A^1 = \frac{M^1\,N^1 \times O\,A}{M\,N}$$

The scale (fig. 14) is placed in fig. 10 at S T (see plan in fig. 12). This scale is usually 4 in. in length, divided into 100 equal parts, the principal divisions being pointed out by numerals engraved over or near them, so as to be readily read by the microscope Q R, and each of these 100 parts is halved by an un-numbered line, so that the whole scale is divided into 200 equal parts. By the addition of a



micrometer screw E F, the scale can be moved backwards and forwards exactly one of these 200 sub-divisions. The circle E F of the micrometer screw is further divided into 100 equal parts by lines properly marked and numbered. Each of these 100 parts is divided into five equal parts by means of an attached vernier (see fig. 14). Hence, the 4 in. scale S T is accurately and visibly divided into 100,000 equal parts.

For city surveying, in laying down transverse lines all chaining is done away with; horizontal angles and levels are taken at one and the same operation. For surveying and levelling in rough, hilly, and thickly-wooded countries, only those who have been obliged to use the theodolite and chain in such places can understand what a boon this instrument will be to others similarly employed. For railways and irrigation purposes, it is equally useful.

The Bell-Elliott Patent Tangent Reading Tacheometer is an improved Eckhold's omnimeter, the latter instrument being shown on page 220. It measures distances and altitudes with accuracy and economy of time and labour, and accomplishes, without being moved, the work of a theodolite, level, and chain, and may be used as a transit theodolite.

The microscope is directed to read the divisions of the divided scale.

Linear distances and altitudes are obtained by this instrument by one and the same operation, with equal precision to the chain or any other known means.

A level is fixed on the telescope so that the axis of the telescope, when required, may be placed parallel to the divided scale.

The divided circular arc, fixed on the common axis, is employed, as in the theodolite, to take vertical angles.

This important surveying instrument is a transit theodolite with an apparatus for measuring by one and the same operation the distance of an object or staff of a determined length, and its height over or under the level line of the instrument.

1st. Place the staff in a vertical position at one extremity of the line to be measured, as at M, N, A in fig. 11, and adjust the instrument at the other end of the line, care being taken that the micrometer of the instrument be set at zero.

2nd. Point the telescope to the upper line on the staff as at M, clamp the telescope thus directed, and then look through the microscope to find what line on the scale S T falls, exactly between the two hair-lines of the microscope. Suppose the division numbered 67 on the scale S T to fall between the two fine hair-lines of the microscope, 67,000 would represent the position on the scale S T, to which the microscope is directed, for 67 stands for 67,000 parts out of 100,000, into which the scale is divided. Should the hair-lines of the microscope fall on an unnumbered division of the scale S T, for example, on the division between 67 and 68, then 500 has to be appended to the lesser of the two numbers, and 67,500 would truly represent the position of the point, on the scale S T, determined by the microscope, while the telescope is directed to the upper line of the staff. But supposing the hair-lines that designate the centre of the microscope to fall between a numbered and an unnumbered line on the scale S T, that is, to divide the space between the numbered line 68,000 and the unnumbered line 67,500 into two parts, the scale must be pressed forward by turning the micrometer circle to the right, until the line 67,500 comes between the hair-lines of the microscope. Suppose the micrometer circle to read 235, that number must be added to 67,500, then the position of the required point on the scale S T is designated by the number of 67,735. The readings on the micrometer circle are plus for elevations and minus for inclinations. After each operation the micrometer circle should be turned to the left back to the 500, to prevent any mistake, as it is made to travel beyond that point each way, in order that the operator may correct any error in the departure point when required.

3rd. The telescope and microscope are unclamped, and a similar operation has to be performed with respect to the lower line on the staff marked N, which is not to be moved until the second observation is made; the first position and adjustment of the instrument are retained, allowing the telescope and microscope to move in the same vertical plane. Let the second reading at N give 66,015.

Let $M\,N = 67{,}735 - 66{,}015 = 1{,}720$.

$$\text{Hence if } M\,N = 10 = \frac{10 \times 150{,}000}{1\cdot720} = 872\cdot09 \text{ feet} = O\,A$$

Therefore for calculating distances we have the following easy rule:—Multiply the length of the staff in feet by the length of the base of the instrument in micrometric equal parts, and divide the product by the difference of the two micrometer readings of the staff, the quotient will be the required distance.

Any error in the departure point may easily be removed by holding the milled head tightly between the thumb and finger, and turning E F to the right or left the quantity required; if too tight to move, loosen the screw in the milled head a little, taking care to tighten it again when set right. The instrument must first be carefully levelled.

Whence for calculating altitudes we have the following simple rule:—Multiply the length of the staff in feet by the micrometric distance between the point of departure and the reading for the lower mark of the staff, and divide this product by the difference of the two micrometer readings of the staff; the quotient will be the required altitude.

Heights are termed positive or negative, according as the readings on the scale are greater or less then the reading which designate the departure point of the scale.

Eckhold, the inventor of the omnimeter, recommends the following form of field book when operating with this instrument (see page 220):—

Station.	Base Line = 1,500,000.				Departure Point at 500,010.						Remarks.
	Staff = 10 feet.		Difference.	Distance. Feet.	Difference.	ALTITUDES.				Reduced Level.	
						Back Sight.		Fore Sight.			
	Upper.	Lower.				+	—	×	—		

It may be necessary to remark that the base scale is not required of any particular length so that it is divided into 200 equal parts, and that the micrometer circle with its vernier divides each of these parts into 5,000 equal parts.

CHAPTER XIX.

TELEMETERS AND LINE RANGERS.

Universal-Telemeter.—Dr. Luigi Cerebotani, an Italian Professor, devised an ingenious contrivance, to be employed as an instrument for land surveying, in which he claims to enable the engineer to ascertain the distances of accessible and inaccessible points (without measuring angles), to determine heights, depths and projection lines from one station only, and to mark out curves in a manner hitherto difficult, except for mathematicians. Cerebotani's surveying instrument consists of a telemeter, which dispenses with trigonometrical calculations. In using this apparatus it is merely necessary to observe a certain point in order to ascertain its distance from the station of the observer by reading off the numbers on the apparatus. By the aid of it we can determine with ease and in a very short time the distance between the two banks of a river, between mountain-tops or steeples, or the distance of any moving point or vessel, and can ascertain measurements of inaccessible and remote ground.

Among other things this apparatus has likewise an arrangement, by which during the operation of measuring a sketch of the ground already measured can be pricked off by means of which a complete plan of the whole country under measurement can be drawn. The combination of three instruments form the so-called "Teletopometer," the invention of Professor Cerebotani, of the Verona University, and consists of:—

(*a*) The telemeter explained above;
(*b*) The appliance for measuring heights and depths, fixed at the top of the instrument;

(*c*) An immovable drawing-board resting on a tripod and independent of the movements of the head of the stand;

(*d*) A ruler metrically divided, and fastened in any lateral direction to the head of the stand and revolving together with the telemeter round the vertical axis of the stand.

This surveying instrument is thus described in *The Builder*. By the aid of the Universal Teletopometer Professor Dr. Luigi Cerebotani claims to be able to measure distances and heights from one station, without the aid of a chain or the necessity of trigonometrical calculation,—and this, with an accuracy represented by a maximum error of a half per cent., or 18 in. in every hundred yards. He claims also to plot his survey at the same time by an automatic arrangement on a drawing-board attached to the stand of the instrument. The instrument itself consists essentially of a horizontal and perfectly rigid steel bar, with horizontal and vertical movements, and to the ends of which are attached astronomical telescopes, one fixed and the other movable in a horizontal plane, both on a pivot and forwards and backwards. The distance between the optical axis of the fixed telescope and the centre of the pivot, becomes the base of a triangle, the apex of which, when an observation is being taken, is the object the distance of which is required.

The peculiarity of the instrument is that its movements record, not the angle taken by the movable telescope, nor any of its trigonometrical functions, but the length of a line parallel to the axis of the fixed telescope, and which forms the side of a triangle similar to the larger one, and the base of which is an aliquot part of the larger base. The length of this line is read with great exactness by the aid of a micrometric screw, and, on reference to a table attached to the instrument, gives the length of the parallel line from the telescope to the object. The distance being known, the height is ascertained in the ordinary way by taking a vertical angle and multiplying the distance by its natural tangent. Attached to the pivot of the instrument, and moving over the surface of a horizontal drawing-board, is a steel straight-edge, the edge of which, moving with the bar of the instrument, is always parallel to the direction of the object under observation, and bears a metrical scale, by means of which its distance may be marked off as soon as found; thus, with a rapidity beyond comparison, with that of the ordinary processes, the relative position of any number of points within the range of the instrument,—which depends only on the distance which separates the telescopes,—may be found and plotted, and, if desired, their height relatively to the level of observation may be noted beside them.

For rough surveys, we believe the usefulness of the instrument will be at once recognised, but for purposes where great accuracy is necessary, we fear that the expressed hope of the inventor that it will supersede theodolites and trigonometry in its employment to topography and curvography is doomed to disappointment.

The Dredge-Steward Omni-telemeter.—This instrument primarily is intended for the measurement of distances for military purposes. As in all apparatus of this class, the result is obtained by triangulation, but contrary to the usual rule, neither of the angles at the base is fixed. Its advantages will, perhaps, be best understood if we explain the principle upon which this class of range-finder usually operates. Let us suppose the distant object to be at a defined point A, and the observer to be stationed at another point B; it is required to find the length of the line A B. By aid of the instrument the observer projects the image of A in a direction at right angles to the line A B, and he notices some distant mark C, which may be a tree, a building, a stone, or any other available object, upon which the image of A is superposed. The line B C is at right angles to the line B A. The observer now distinguishes the point B by leaving there a mark, such as a stick or bayonet, and he moves away from it, keeping rigidly in an extension of the line C B. By aid of another part of the instrument, which reflects light at a somewhat smaller angle than that first used, the observer from time to time projects the image of A towards the mark C. At some point D, these two will coincide, and a

Fig. 1.

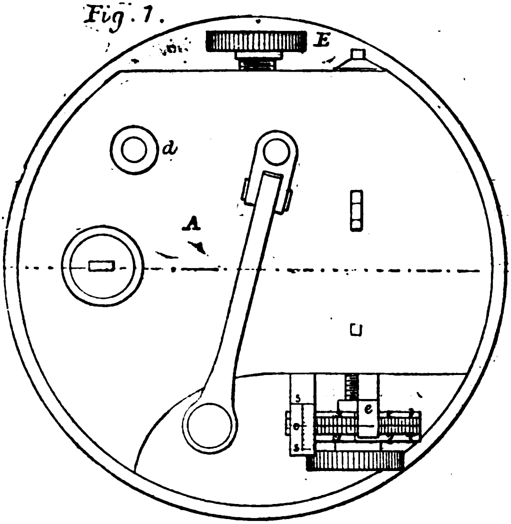
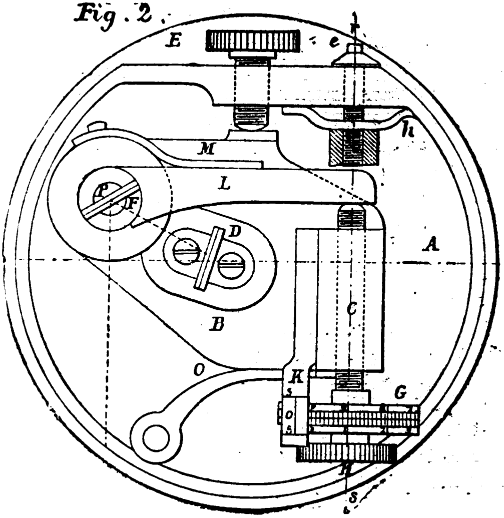


Fig. 2.

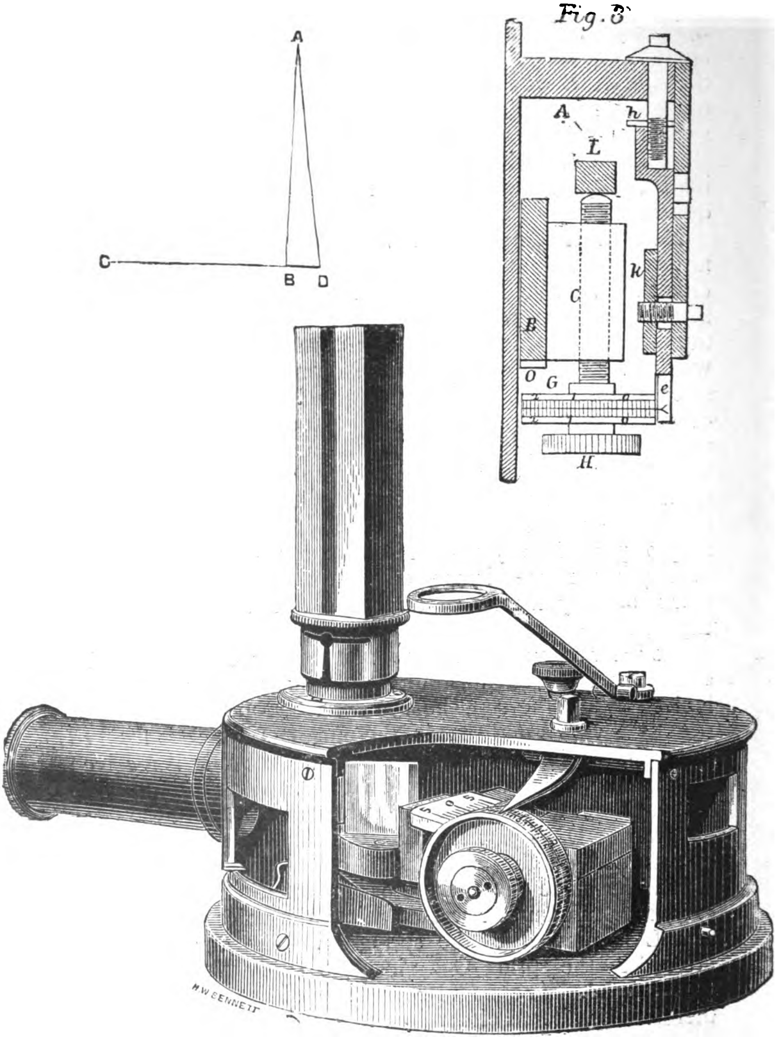


triangle A B D will be formed, of which the angle B is a right angle, the angle D has a known value, while the angle A equals 90° minus D. If the base B D be measured, the side A B can be easily calculated, but to render this operation as simple as possible, the angle D is chosen of such a magnitude that A B equals 50 B D, or 100 B D. Thus when the point D is found, all that remains is to pace back to B, and multiply the result by 50 or 100 as the case may be.

Now in the omni-telemeter the angle at B is not necessarily a right angle, but may vary as much as 8° on either side. The effect of this is that a mark may almost always be found at once. It may very well happen with the ordinary instrument that the observer must move backwards or forwards a considerable distance before he can hit upon a mark suitable for his purpose. But with a latitude of 16° it must be a very desolate scene which does not provide some prominent object within a reasonable distance. When the mark has been chosen the observer moves back from it (if this be impracticable he may move towards it) a certain definite distance, either 50 yards, or a multiple or aliquot part of 50 yards. He then adjusts the instrument to superpose the image of the distant object on the mark, and by means of an index and a table reads off the distance.

We will now explain the construction of the instrument by aid of the annexed illustration (page 229). The observer looks through the sight hole or the telescope (not shown in the detail views) and sees in the mirror D, which is fixed to the case, the image of the distant object; this is received on the mirror P and reflected on to D. Over the top of D he sees the selected mark through an aperture in the case. The mirror D, as just mentioned, is fixed, but the mirror P is mounted on the arm F and concentric with its pivot. Upon the same pivot there is mounted another arm B carrying a micrometer screw against the point of which the arm L is pressed by the spring M. The arm B is itself pressed by the spring O against the screw E, which has a milled head. The angular position of the mirror E can therefore be altered either by the screw E or the screw G.

Fig. 3



The former screw is used in the first operation of projecting the image of the object on to the mark, and the second in readjusting the image when the base line has been measured. This latter screw has a head G divided into 100 parts, and moving in front of a fixed scale divided into ten spaces, five at each side of the centre line. At the commencement of the observation this head is adjusted to the zero mark by placing its centre circumferential line opposite the central division of scale *k*. This sets the arms L and B at a definite angle, and then by means of the screw E, the arm B is set to a fiducial mark *e* on the case (fig. 3). If this mark should get displaced it can be readjusted by the screw *h* shown in fig. 3, which is a section in line *r s* (fig. 2).

The method of using the instrument is as follows :—The head or drum G is set to its zero point both in relation to the scale K and the mark *e*. The instrument is then put in position so that the observer looks towards the mark. At the same time he sees the image of the distant object in the mirror D, and by turning the screw E with the left hand he can make the image align with the mark. He then moves away from the mark (or towards it), a distance of 50 yards, or an aliquot part of that distance, and then makes a second observation. Again, looking at the mark he turns the screw with the divided head G until the mirror P is moved sufficiently to bring the image of the object again into alignment with the mark. The number of divisions of the drum and of the index are then read off, the former by aid of a lens, mounted in an arm on the top of the instrument. For example, if the fine line on the drum is between the second and third line of the index, and the edge of the index intersects the cross divisions on the drum at 65, the reading is 265. By aid of a table on the instrument the range can be read off directly in yards, if the base selected was 50 yards. Suppose, for instance, the base was 75 yards, then the reading must be increased by 50 per cent.; if 100 yards it must be doubled, and so on.

The instrument will also show the distance of an object by measuring the two inside angles of a triangle, neither of which need of necessity be a right angle, and this without any calculation, as means are provided in the telemeter by which the result is mechanically computed; and the index number shown at the second observation is the only one that is referred to the table affixed to the instrument, and gives the range. This offers facilities for range-finding from the tops of hills, in forts, or batteries, where it would be impossible to find any object (C) to form the extension of base necessary by the method described above.

It is, moreover, easy to take the range of an object without measuring the base (by chaining or pacing), and this allows of the two points B D being separated by a gully, swamp, or other obstruction in a straight line that can be got round but not across. The sum of the two index readings at B and D divided into the constant of the instrument, giving the range. For coast batteries this is considered a great advantage.

If two instruments are employed that have previously been set in exact adjustment the distance of moving objects from a fixed point can be obtained, or that of a stationary object from a moving one (such as a vessel). All that is necessary is for the two observers to be placed a known distance apart, and for each, by turning the micrometer screw, to keep the object and the other observer aligned, and at a given signal to take the reading. The sum of the two readings gives the index number to be referred to the table of ranges as in previous instances.

A modification of this instrument called the "Simplex Range Finder" has been devised. When this is used one of the angles at the base of the triangle is a right angle, and the other has such a value that the proportion of the base to the perpendicular is as 1 to 100. The angular point of the mirror is altered by a screw in a nut as before, but instead of this screw having a divided head, it carries a plate, which can oscillate through such a part of a circle that it alters the angle of the mirror by the required amount. A stop arrests the rotation of the plate.

The advantages of the omni-telemeter are: (1) it does not require the use of an exact right angle; (2) it can be used in various ways, according as the situation is open or confined; (3) the direct gaze can be directed either to the object or the mark, as most convenient; (4) it can be applied to find the distance of moving objects.

By using the instrument on its edge and suspending the plumb-bob supplied with it from the hook in socket mount, vertical angles can be measured and heights of objects obtained. This makes it valuable for ascertaining the altitude of hills, trees, rocks, &c. The method of using is to hold the instrument firmly on a level with the eye, so as not to sway backwards or forwards (a stand or rest being useful for the purpose), and, dropping the plumb, look at the object and, with a compensating screw bring the base of the object and plumb-bob to coincide by reflection. Then turn the micrometer screw (previously set to zero on both indices) until the summit of the object coincides with the plumb-bob. The number of the index reading referred to in the table of heights and angles represents the vertical height.

There are many other ways of using the instrument which an observer will readily become accustomed to after he has mastered the methods previously enumerated, and the advantage of these facilities is that no matter from what position a range is required it can be obtained by the omni-telemeter with a little practice.

Mr. J. H. Steward, of 406, Strand, London, who assisted the late Mr. William Dredge in its construction, is the manufacturer.

Wells' Pattern.—Fig. 15 (page 235), illustrates Wells' apparatus, which can be fixed to the diaphragm of any levelling telescope for the purpose of judging distance when taking trial levels without chaining the horizontal distances. It can also be introduced for the purpose of a check on chain measurements. The vertical distance between the horizontal cross-hair and the needle-point, A, can be regulated within the limits marked "Traverse of needle" in the diaphragm by means of the micrometer screw B, the top of which, as shown in the plan, is graduated to serve as a reference for setting the needle-point to any given distance. The index-pointer to this graduated circle is fixed upon the front of the breech end of the telescope, over the eye-piece, as shown in the

WELL'S APPARATUS FOR JUDGING DISTANCES

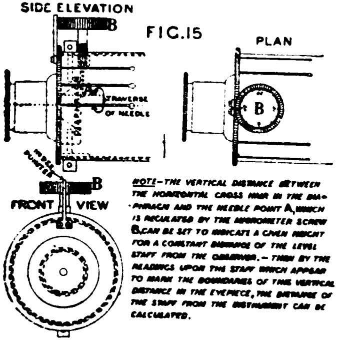
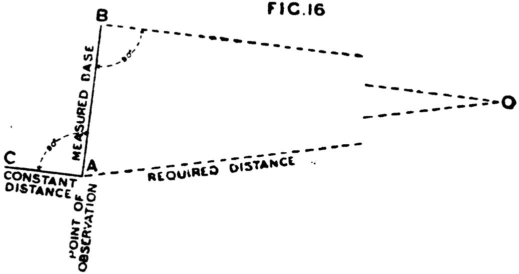


FIG. 15

NOTE—THE VERTICAL DISTANCE BETWEEN THE HORIZONTAL CROSS HAIR IN THE DIAPHRAGM AND THE NEEDLE POINT A, WHICH IS REGULATED BY THE MICROMETER SCREW B, CAN BE SET TO INDICATE A GIVEN HEIGHT FOR A CONSTANT DISTANCE OF THE LEVEL STAFF FROM THE OBSERVER.—THEN BY THE READINGS UPON THE STAFF WHICH APPEAR TO MARK THE BOUNDARIES OF THIS VERTICAL DISTANCE IN THE EYEPIECE, THE DISTANCE OF THE STAFF FROM THE INSTRUMENT CAN BE CALCULATED.

PRINCIPLE OF THE RANGE FINDER

FIG. 16

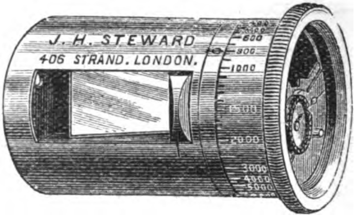


front view. The needle, which is worked up and down by the micrometer screw B, travels in the same vertical plane as that in which the cross-hairs are fixed. To set the needle, measure any distance, say 100 ft. upon level ground, set up the level so that the telescope stands over one end of the measured distance, while the staff is held at the other end. Focus the telescope accurately, and move the needle-point A in the diaphragm by the screw-head B, until exactly 1 ft. of the staff image is enclosed between the needle-point and the horizontal cross-hair in the diaphragm. In this way a datum "distance reading" may be obtained from which other distances of varying lengths can be easily calculated. The divisions upon the top of the screw B (see plan), where the index-pointer touches, should be noted for future reference.

Fig. 16 (page 235) illustrates the principle upon which range-finders are constructed. If AO equals the distance to be found, three well-defined points or pegs are employed, and B is so placed that the angle ABO is a right angle, while C is placed perpendicular to AB at a constant measured distance in order to find the length of AB by actual measurement. The surveyor standing at A, observes the quantity by which BAO is short of a right angle, and the measured base, AB, being arrived at, the instrument determines BO automatically. Practically, as AB is very short compared with the length of BO, the distance AO is equal to the distance BO. Thus the measurement mechanically of the non-parallelism between BO and AO determines the distance of the point O. The base may be taken any convenient length, but it is evident that accurate results can only be obtained when the distance is small compared with the distance required to be found. Among the best instruments may be mentioned the Bate range-finder, the Watkin range-finder, and Labbez telemeter.

Labbez Telemeter.—This is an instrument designed to give, without any calculation whatever, the distance of objects from 250 to 3,000 yards.

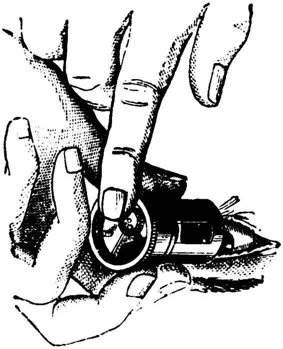
The base, usually 30 yards, may be paced, when approximate accuracy is sufficient, and time is of consequence. The length of base may be half (viz. 15 yards) one-third (10 yards), or double (60 yards), and the results will be half, one-third, and double respectively of the distances shown on the drum of the instrument.



ACTUAL SIZE.

The chief merits claimed for Labbez's telemeter are, that it does not require an absolute right angle to be laid out, and it is not dependent on seeing a definite size object (such as a man standing erect). This form of telemeter is a useful surveying instrument, and is used in the following manner (see figs. 1, 2, and 3).

Fig. 1.



1. Open the slide at the end of the cylinder.

2. Set the small-toothed wheel so that the zero is opposite the zero-line, also set the revolving part of the cylinder, so that the zero upon it is exactly upon the zero-line of the fixed portion of the cylinder.

Fig. 2.

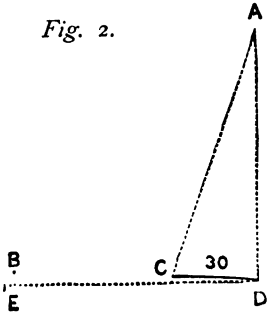
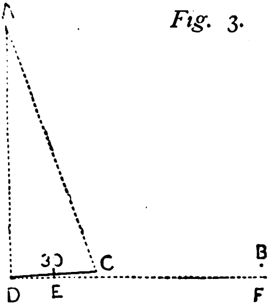


Fig. 3.



3. To find the distance of A (fig. 2), stand at D, face to the left, E, and notice an object (say B) of a prominent nature (alluded to hereafter as the mark) as near as possible at right angles to the object A of which the distance is required. Hold the instrument with the thumb and finger of the left hand, as shown at fig. 1, in such a way that the oblong opening is quite free, and place it to the eye: look through the hole at the small end of the instrument at mark B, and with the fore-finger of the right hand, turn the small-toothed wheel until coincidence between the range object A and the mark B is obtained; in other words, A is reflected on B. A slight rotary motion of the instrument between the thumb and finger will bring the reflection of the object into the right level, and a slight inclination or declination will allow of the mark being seen above the mirrors through the aperture in the end.

4. Fasten the end of the line into the ground at D, by passing one of the arrows through the loop, and walk to the other end (C) of the 30 yard line in the direction of B. Let some one standing exactly over D set the observer exactly with B (by calling out right or left until the right side of the head of the observer covers the mark B).

5. The observer, facing the same way as in the previous operation, now looks at B revolving the end of the cylinder until the object A is reflected on B.

Directly this is done, the line opposite the fixed zero will represent the distance of the object A in yards.

Fig. 3 is shown the reverse way to that generally adopted; that is looking right instead of left.

Should it so happen that no natural or other prominent object is to be found somewhere near at right angles to A for use as a mark, then a man can run out, and hold up a mark to any position near the right angle, at any distance over 60 yards.

The observation may be made the reverse of the above if no suitable object is found to the left (see fig. 3); the only thing to remember is to turn the instrument over, and follow the same instructions as above, reading right for left.

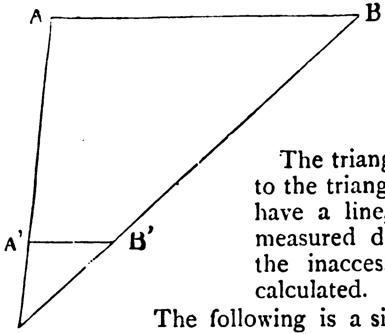
It is recommended for all distances that are supposed to be more than 1,000 yards, to use a double base (60 yards), and for distances that are beyond 2,000, a treble base (90 yards).

Observations may be checked by stopping at 15 when using the 30 base, and taking an observation there.

The mirrors within the instrument are set at 45° but the movement of the small-toothed wheel by the first finger of the right hand alters the angle by pressing in the horizon-glass so that the angle A D B may deviate from a right angle 2½° to the right or left hand. The revolution of the end cylinder moves a cam, and by this cam action, a movement is given to the index glass until the required coincidence of the objects B and A in the mirrors is obtained. This instrument is frequently used as a range-finder, for which it commends itself on account of its portability.

The telemeter also enables the observer—(1.) To raise a perpendicular from a point; (2.) To draw a line from a point perpendicular to a straight line; (3.) To draw a straight line parallel to a given straight line; (4.) To prolong a straight line beyond an obstacle; (5.) To measure a surface of land; (6.) It can be used to facilitate the making of plans; (7.) Also to assist in making military reconnaissance of a zone of land or of a road in time of peace or war.

Fig. 4.



The instrument will determine the approximate distance apart of two inaccessible objects by laying out a triangle as follows :—

The triangle A' B' C being similar to the triangle A B C (fig. 4), we have a line, A' B', which can be measured directly, and from which the inaccessible distance can be calculated.

The following is a simple method of carrying out the above instructions :—

Find with the telemeter, by the method previously described, the distances of A and B from C. Place a man or picket at one-tenth of the distance of C B, *i.e.* at B', in a line with B. Set the telemeter to its zeros and walk in the direction of A from C, keeping in dressing with A until B' is reflected on A. The distance between A and B will be ten times that of A' and B'.

To measure the width of a River.

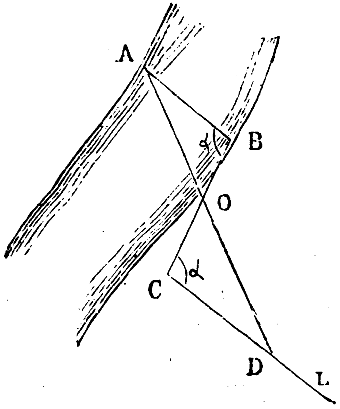
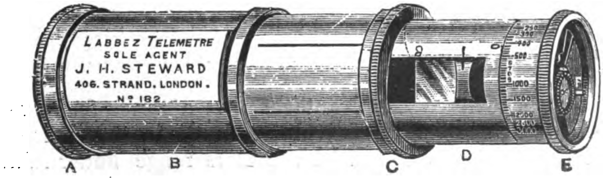


Fig. 5.

Any other proportion can be taken, but if the point at one-tenth is accessible, that is the most convenient, being a decimal equivalent. To measure the width of a river, (fig. 5) set out an imaginary line, C L, by pickets, parallel to the breadth of the river A B, by forming two equal angles at B and C, then draw a line through O at the half of the line C B till it touches the line C I, (at D), the distance from D to C is the same as the breadth of the river.



In the annexed view the telemeter detaches from the telescope by holding firmly the tube C and turning D portion to the left, after which it will slide off.

This fitting, in principle, is like a bayonet catch. The object-glass of the telescope is at C, and the eye-piece at A. The focus is obtained by sliding in the tube attached to mount C. The fitting D containing the mirrors, &c., slides into C for portability. The button F is to correct for the object used as a mark not being a right angle, and the drum E revolves and shows the range opposite zero.

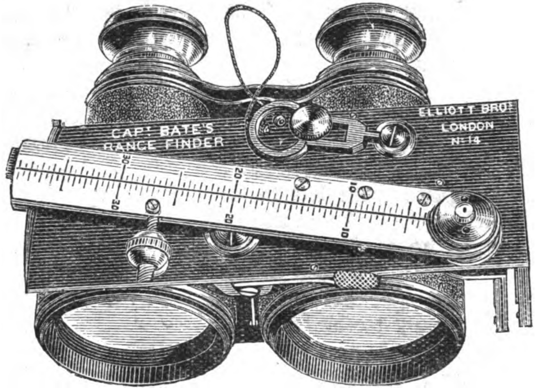
The advantage of the addition of telescopic power is not only that more distant objects can be observed and the range of the same found, but also smaller objects can be taken, and more perfect direction under all conditions obtained.

The Bate Range Finder.—This instrument was invented by Capt. C. McGuire Bate, R.E.

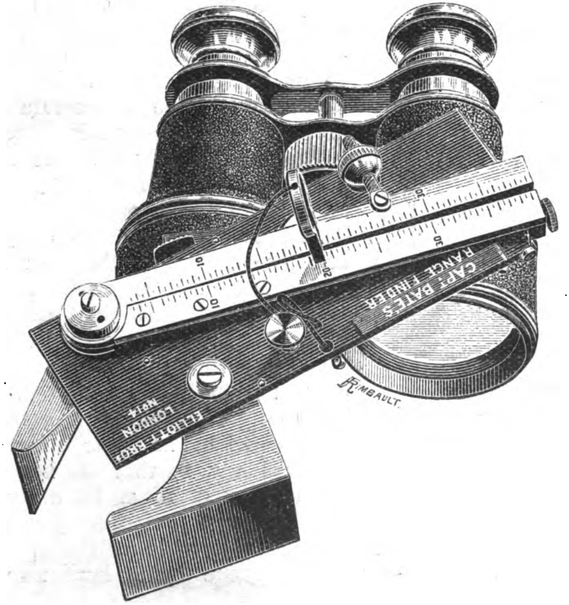
The following description of this range finder is extracted from "Infantry Fire Tactics," by Capt. C. B. Mayne, R.E., published by Messrs. Gale and Polden, Chatham.

"The principle on which this range finder works is, that it actually plots on a brass plate, by means of two graduated limbs and a movable gauge, the triangle formed by the two ends of the base and the object whose range is required. This theoretically allows of any latitude in the choice of the direction for the base, but practically the instrument only allows of the base lying anywhere between 30° on either side of the perpendicular to the range; it is permanently attached to a pair of field glasses. The instrument gives the range in multiples of the base, which has therefore to be measured. Two men are the most required to work it. It is easily learnt; it does not require any adjustments to be made, and it can be fitted to any pair of field glasses. The method of using a gauge to determine the multiples of the base from the graduated limbs is one of the most accurate mechanical methods known for measuring small dimensions.

"One of the greatest advantages that a range finder can have is to allow of a considerable latitude in the choice of the direction of the base, and the Bate range finder fulfils this condition. The great disadvantage of having a fixed direction for the base is that in a defensive position on the crest of a ridge or plateau, the fixed direction of the base


CAPT BATE'S
RANGE FINDER
ELLIOTT BROS
LONDON
No 14
30
20
10
30
20
10

Closed.


CAPT BATE'S
RANGE FINDER
ELLIOTT BROS
LONDON
No 14
30
20
10
30
20
10
RIMBAULT

Open.

may be such that one end of the base is behind the crest line, and the distant object whose range is required cannot be seen from it."

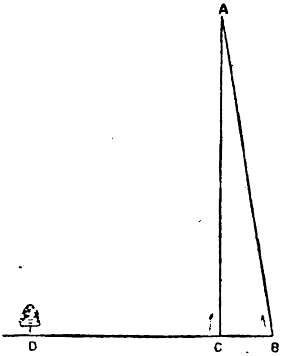
Directions for Use.—1. Clamp the range finder (whilst closed) firmly, but without using undue pressure on the field glass, having the word "Front" over the object-glasses.

2. Press the spring catch at the side of "Front," and revolve the plate from left to right about 150°, until the spring catch again locks on the centre.

3. Loosen the small milled-headed screw at the end of the divided arm. The first mirror is now turned outwards as far as it will go, and the second mirror inwards at an angle of about 45° to the first.

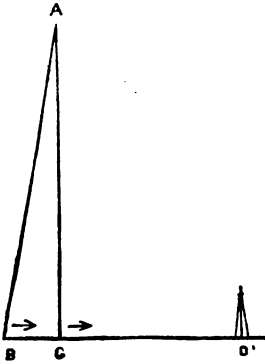
The instrument is now ready for use:—

The observer at B first directs the glass to the object A, whose range is required to be found, and the second mirror is moved by hand to catch D, any object—the more distant the better—at about right angles to B A (or within say 15° or 20°). It is next necessary to make an accurate contact of A and D, which is done by turning, with a finger of the right hand, the milled nut on the screw attached to the graduated arm. This being done, the loose arm is brought close up to the other arm and clamped. The observer now measures any convenient distance B C on the same straight line towards D, and again at C, makes contact with A and D by turning the milled nut from left to right. The angle between the graduated arms will be equal to half the difference between the angles A B D and A C D, that is, half the angle subtended by the base B C at A. In order to read off the range on the instrument, the gauge is inserted between the divided arms as far as the opening will allow, the face of the gauge being kept true to the divisions on the arms, the reading at the point where



the gauge clips between the arms giving the multiple of the base of the range.

1. Base B C = 100 ft.
   Gauge reading = 27·5
   Range = 27·5 × 100 = 2,750 ft.
2. Base B C = 30 yards
   Gauge reading = 24·5
   Range = 24·5 × 30 = 735 yards.
3. Base B C = 50 paces.
   Gauge reading = 32·5
   Range = 32·5 × 50 = 1,625 paces.
4. Base B C = 58 ft.
   Gauge reading = 27·5
   Range = 27·5 × 58 = 1,595 ft.



If it be found more convenient to take the distant object D′ to the right, the first observation at C and the second at B are taken in a similar manner to that before described, but by turning the glasses towards D′ and catching A in the mirror, thus working by reflection of object A, whose range is to be found.

It is of the greatest importance that the base should be measured exactly on the line to the distant object D or D′, that is, on the line B D or C D′; this can be done by taking an intermediate object of some kind between B and D or C and D′, and keeping this point and D or D′ in line with each other whilst walking from one base point to the other.

Capt. Willoughby Verner, of the Rifle Brigade, in his "Rapid Field Sketching and Reconnaissance," (published by Allen and Co., 1889), states that when in the Soudan he constantly felt the want of a range finder both for topo-

JAHN'S TRIPO

FIGURE 1

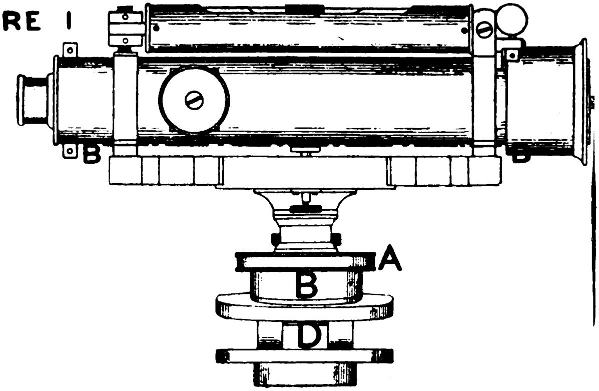
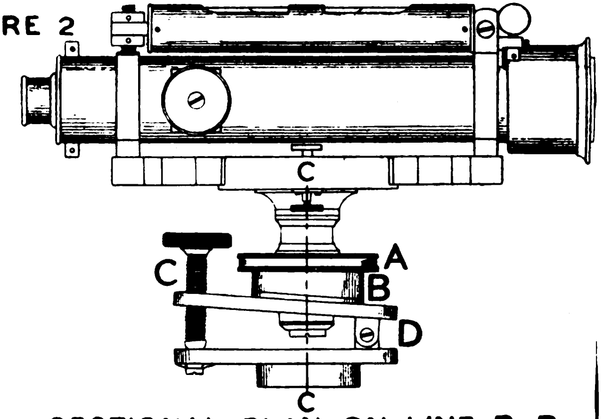
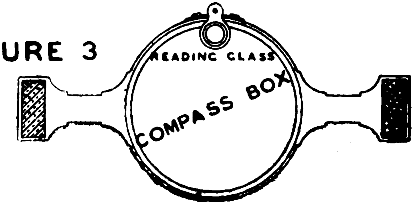


FIGURE 2



SECTIONAL PLAN ON LINE B-B

FIGURE 3

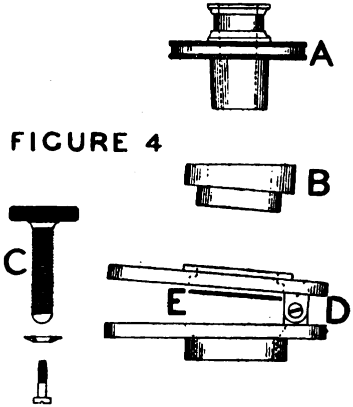


D HEAD

[*Field Work and Instruments,* *pp.* 245, 246.

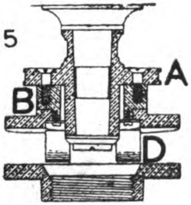
DETAILS

FIGURE 4



SECTION ON LINE C-C —

FIGURE 5

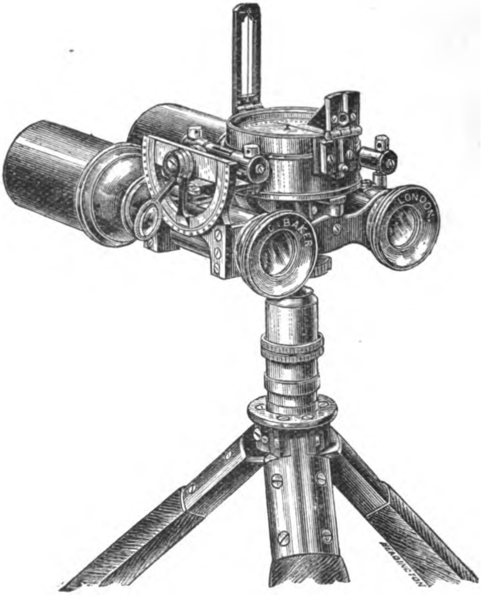


NOTE THIS INSTRUMENT IS SET LEVEL BY BEING PLACED ALTERNATELY IN THE POSITIONS SHOWN IN FIGURES 1 AND 2 - THESE POSITIONS ARE AT RIGHT ANGLES TO ONE ANOTHER - THE ADJUSTMENT IN FIGURE 1 IS EFFECTED BY MEANS OF THE WEDGE SHAPED CONNEXION B WHICH S TURNED BY THE MILLED EDGE A AND THE ADJUSTMENT N FIGURE 2 BY MEANS OF THE SCREW C —

IN REVOLVING THE TELESCOPE ON ITS AXIS THE EDGE SHAPED PORTION B MUST BE MAINTAINED IN POSITION BY HOLDING THE PIECE A AS NO CLAMPING ARRANGEMENT IS PROVIDED —

graphical and technical purposes, and he also emphasizes the importance of carefully examining distant objects with a field glass when about to select such military points as forward stations, so as to avoid the possibility of mistake.

The **Ashenden's Reconnaissance Binocular** is a combination instrument, consisting of binocular field glass, prismatic compass, Abney level and level with stadia lines, and made at the suggestion of Mr. Percy Ashenden, P.W.D., Cape Town, South Africa. It can be used by military officers, civil engineers, surveyors, &c., for general prospecting and reconnaissance work. The binocular field glass (magnification × 4) is provided with a focussing adjustment actuating the object glasses, a diaphragm with one vertical and three horizontal lines in the right-hand tube (the distance between the two extreme horizontal lines being 1 in 100), and a levelling bubble attached to the

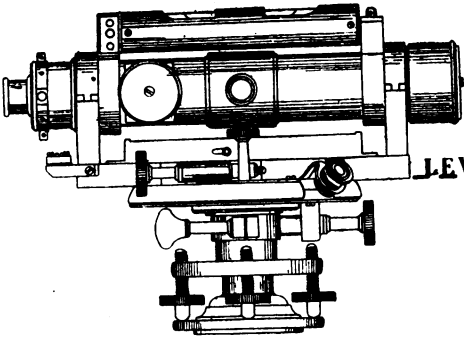


outside, thus enabling the telescope to be employed for levelling or judging distances. The left-hand tube contains a reflector on which the bubble of the Abney level can be seen. The arc of the Abney level is divided 1-1, and can be employed from 0-40° in either direction; the usual vernier and adjustable reader is also provided. A very delicate movement can be given to the vernier by holding the extremities of the bubble between the thumb and finger. When not required, the reflector, which is hinged at the upper end, can be swung out of the field of view by moving a small lever at the side of the tube. To prevent damage to the edge of the reflector it is advisable to withdraw the eye-piece slightly before moving the lever. The eye-pieces being adjustable, the stadia lines and bubble can be accurately focussed. It also contains a prismatic compass, 2 in. diameter, with aluminium ring attached, as shown in the illustration, but which is reversed when not in use. It can be fixed either in the direction of the field glass, or at right angles to same. It is held in position by a bayonet catch, but can be easily removed when required to be used separately. The glass of the compass is ruled with a white line which can be rotated to any point, thus allowing the direction of the line of march to be set. A screw socket is placed under the centre of the prismatic compass, to which a light mahogany tripod with universal ball head, capable of being rotated, is attached. The instrument is supplied in a solid leather sling case, either brown or black, with loops for attachment to belt. Weight of instrument, 1 lb. 10 oz. Size of 6½ × 4 × 2½ in.

Jahn's Level—This instrument is illustrated by figs. 1 and 2 (pages 245-6), and consists of a levelling telescope mounted upon the ends of a horizontal bar, which is supported upon a tripod head, the details of which are shown in figs. 4 and 5. The telescope is set level by being placed alternately in the positions shown in figs. 1 and 2. These positions are at right angles to one another. The adjustment of the longitudinal bubble in fig. 1 is effected by means of the wedge-shaped connexion marked B, which is turned horizontally by the milled edge marked A, and the adjustment in fig. 2 is effected by means of the vertical screw marked C. The

ADIE'S COMBINED L

·FIGURE 1·



FIGUR

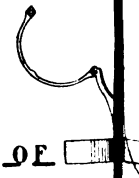


FIGURE 3

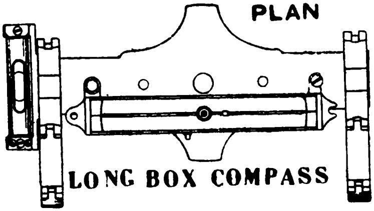


FIGURE 4

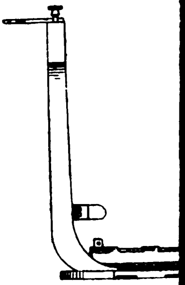


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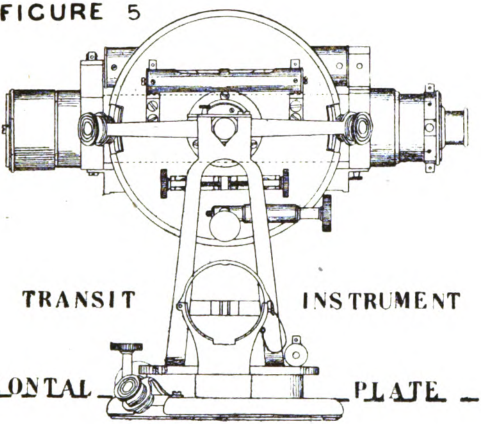
FIGURE 5



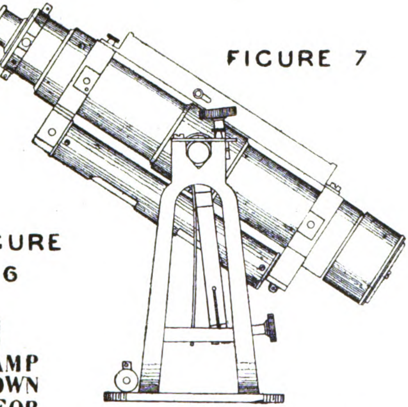


FIGURE 7

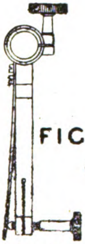


FIGURE 6

GERMAN CLAMP USED AS SHOWN IN FIGURE 7 FOR STEADYING THE TELESCOPE, WHEN THE VERTICAL CIRCLE SHOWN IN FIGURE 5 IS DISPENSED WITH.

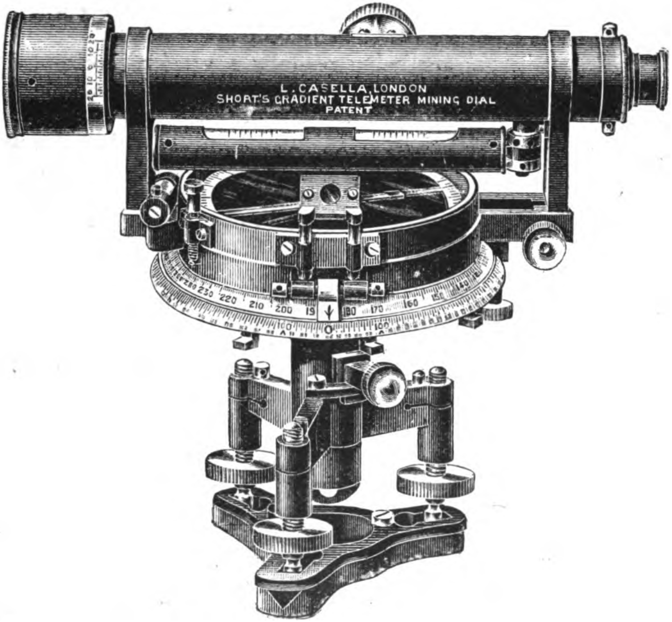
comparative tightness of the adjustment may be effected by regulating the screws below the wedge-piece plate and of that fixed to the main body of the vertical axis cone. When attention is paid to this, the revolution of the telescope may be effected without disturbing the wedge-piece plate. Otherwise it must be held in position as stated upon the note in the diagram. This interesting telescope was originally made by Messrs. Elliott Brothers.

Adie's Combined Level and Theodolite commends itself upon account of its portability. Fig. 1 (pages 249, 250) shows the instrument in use as a level; fig. 2 the V support for the telescope when employed for taking levels; fig. 3 shows the position of the Y supports open ready to receive the telescope, and also shows the magnetic needle with compass-box; fig. 4 illustrates the upright frames which are attached to support the telescope when required to be used as a theodolite, forming, with an attached vertical circle, a transit instrument as in fig. 5; fig. 6 shows a clamping arrangement which can be substituted for the vertical circle; and fig. 7 shows the application of this clamp to the telescope, also the magnetic compass attached to the top of the telescope. All the divisions upon the primary scale surrounding the limb of the instrument are covered, except where the verniers occur, and the tangent screws are also covered. The magnifying glasses for reading the verniers are screwed on to the instrument, which prevents their liability to fall off while the instrument is being carried from one station to the other. In replacing the telescope into its bearings for use as a level (fig. 1) there is an arrow head, half upon the eye and collar of the telescope and half upon the clip. These being made to coincide when clamped, show the cross-hairs in the diaphragm-plate to be horizontal and vertical. The centre portion used for theodolite work can be clamped up when the instrument is required to be employed as a level only. The bearings of the needle in the compass-box are referred to the primary scale of divisions upon the horizontal limb for registration of the bearing of any special station under observation.

The Gradient-Telemeter Mining Dial of Mr. G.

Short is a modification of the gradient telemeter level adapted to mining work. Its special features are:—

1st.—That the gradient limb has an additional arc, on which arc, are marked the horizontal angles observed apart from the compass readings of these horizontal angles. This enables the angular bearings of objects, or of headways and galleries in mines, to be learned or fixed apart from the magnetic bearings of these same objects.



This property of the instrument avails especially in districts or mines where ironstone is known or supposed to exist, the errors resulting from the attraction of the needle to masses of iron being thus entirely eliminated.

The zero of departure for horizontal angles can be fixed from one compass-bearing, if the needle can be so far relied on; or, any object can be made the zero of departure when the various horizontal angles of other objects (or bearings of headways and galleries) result from their difference to the zero object.

Horizontal angles can thus be taken far more rapidly than by needle readings (even if needle readings could be relied on), for no time is lost whilst waiting until the vibrations or oscillations of the compass-needle cease.

This delay in work is well known to all mining engineers as being most trying, and often results in a "snap" observation of the vibrating needle being taken to save time, when the chances of serious errors ensue.

The additional arc being read by a vernier, horizontal angles can be taken to five minutes—if the true compass bearing of any one object is known, the actual magnetic bearing of all other objects result, without calculation, from their relative position to the one known compass bearing.

2nd.—The gradient limb of the instrument has marked on it all gradients or slopes from 1 in 500 to 1 in 24. This series would include all the gradients used in mines, either for the fall in galleries necessary for drainage, or for the use of self-acting trollies for loading-up purposes, or similar requirements, but any other set of gradients can be marked which may be desired.

These gradients, or slopes, are fixed in an instant by a simple movement of the instrument on its axis, when the gradient reading is given by reference to an index point read by the eye as easily as the minutes on a watch-dial are read by the minute hand—no vernier being necessary for these gradient readings.

For gradients as above, no distances have to be measured, and no levels have to be taken as in the usual method of learning slopes.

3rd.—In addition to this, the gradient limb enables distances being obtained or set out entirely without the use of a tape, fathom rod, or chain. These distances are accurately and speedily ascertained by simply reading a levelling staff, or a suspended tape, placed at the distant object or position.

Mr. L. Casella, the maker of these instruments, supplies the following table for use, with examples of subtenses, from 2 ft. to 10 ft.

FOR DISTANCE 315 FT.

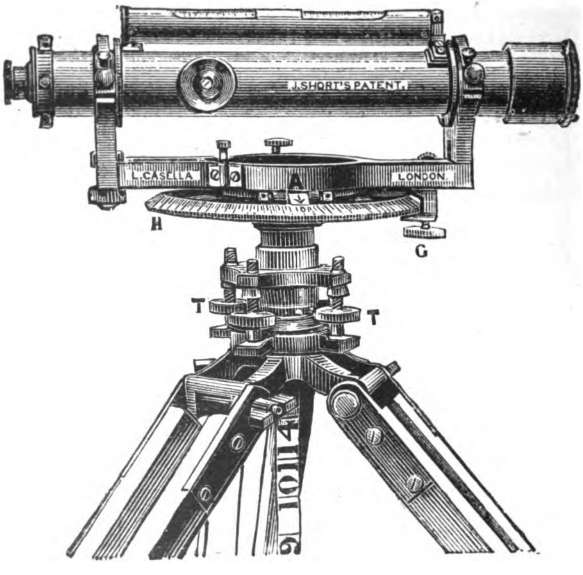
For Subtense	Integers as Divisors.	Examples Selected.	Resulting Gradient Pairs.	Giving Subtense on Staff.
4ft. ..	Any two, 4th in succession ...	5 & 9...	63 & 35 ...	4·00 ft.
5ft. ...	,, 5th ,, ...	5 & 10...	63 & 31½ ..	5·00 ,,
6ft. ...	,, 6th ,, ...	9 & 15...	35 & 31 ...	6·00 ,,
7ft. ..	,, 7th ,, ...	5 & 12...	63 & 26¼ ...	7·00 ,,
8ft. ...	,, 8th ,, ..	6 & 14...	52½ & 22½ ...	8·00 ,,
9ft. ...	,, 9th ,, ...	6 & 15...	52½ & 21 ...	9·00 ,,
10ft. ...	,, 10th ,,	10 & 20...	31½ & 15¾ ...	10·00 ,,

The greater the subtense used, the more accurate will the "setting-out" be, and in all cases the nearer to the foot of the staff the two readings are taken, the more correctly will the line "set-out" be. If the staff readings are carefully taken, distances can be "set-out" by this "subtense" method across water or rough ground where the chain cannot be used at all. Distances thus "set-out" are always horizontal distances, no matter what the rise or fall of ground may be. As a rule, gradients between G 10 and G 60 give the quickest and best results.

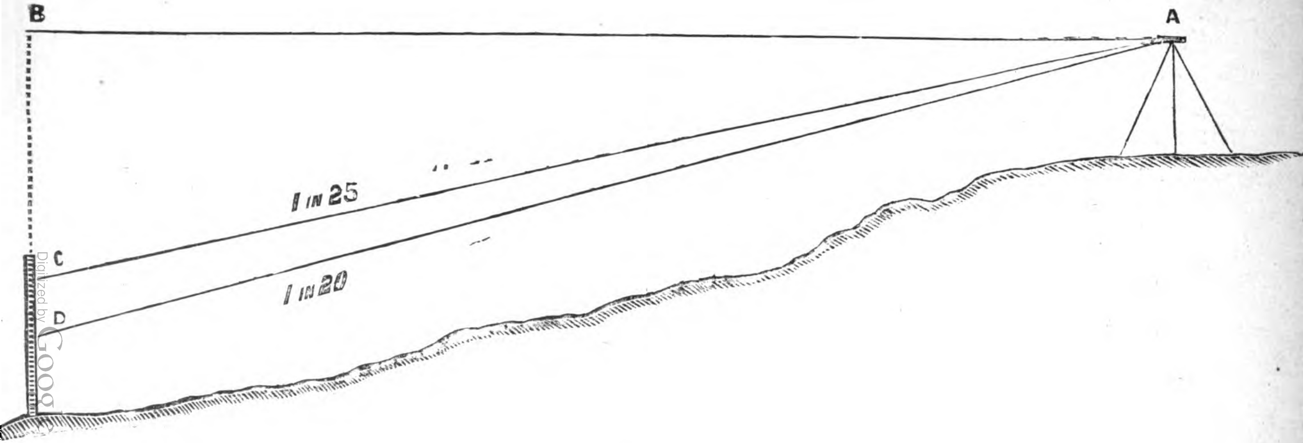
Major Green, R.E., in a report of the trial of this type of gradient-telemeter level by the Royal Engineering Committee, at Chatham, in the spring of 1892, furnishes the following abstract:—

No. of Station.	Gradients used	Chained Distance.	Error by Grad.-Tel. Level.		Remarks.
			Minus.	Plus.	
		Feet.	Feet.	Feet.	
Back	17 and 34	115·50	0·75		
I.					
Forward.	Level & 25	288·42		0·33	
Back	Level & 50	239·25		0·25	
II.					
Forward.	Level & 60	* —	—	—	* This was a bad reading due to smoke obscuring the staff.
Back	Level & 30	362·34		0·36	
III.					
Forward.	20 & 30	278·52	0·12		
Back	20 & 30	435·60	nil.	nil.	A. O. GREEN, Major R.E.
IV.					
Forward	Level & 20	119·46		0·14	
Distance by Chain ...		=1839·09	0·87	1·08	
,, Gra.-Tel. Level		=1839·30		0·87	
Difference		= ·21		0·21 ft. = 2½ in. about.	

RESULT.—In the "traverse," or distance measured above with the gradient-telemeter level of over 613 yards, the error or difference compared to the land chain measurement was only about 2½ in.; this means that in one mile of ground measured with this instrument the difference would be less than 8 in. The adjustment of the reading index to the gradient limb is effected thus:—Let a line be accurately measured on level ground (say 200 ft.), set up the instrument at one end of this line and a levelling staff at the other end. Then take the staff readings, using the zero and gradient 100



If the result differs from the length of the line (200 ft.), move the index to the right or to the left by the two screws which bear on the side of the index until exactly 200 ft. is given by the observation, when the index will be in perfect adjustment for gradient 100, and also for all other gradients


B
A
1 in 25
C
1 in 20
D

marked on the limb. It will be understood that the index being moved slightly to the right or left, increases or lessens the staff reading from which the linear distance is got.

The method of getting horizontal linear distances, and also levels up to 100 ft. on sloping ground, when the levelling staff is wholly below or above the horizontal line of sight,—without moving the staff or the instrument, with a Short's gradient-telemeter level is shown by the following example :—When the instrument is levelled and the horizontal line of sight AB is above the top of the 14 ft. staff, proceed as follows :—Loosen the clamp and move the telescope until the index reaches gradient 100, and sight the staff—if the line of sight is still above the staff move the telescope and index farther until the upper part of the staff is visible through the telescope—suppose the index is then near gradient 28, move it again until it cuts exactly gradient 25 and take the staff reading at that gradient—suppose this to be 13·86 ft.

Then move the index on to G20 and again read the staff —let this reading be 8·45 ft. and take their difference thus :—

$$\begin{array}{rr} G25 = & 13{\cdot}86 \\ G20 = & 8{\cdot}45 \\ \hline \text{Diff.} = & 5{\cdot}41 \end{array}$$

Eliminate the decimal point and the horizontal linear distance AB, as in the above illustration, is 541 ft. without any calculation being necessary for hypothenusal difference or for other reductions.

Any pair of gradients in the following list below will give by the difference of their readings the horizontal distance in this manner, the choice of gradients being determined by the nature of the ground. The level of the Station B is got by adding $\frac{1}{20}$th the linear distance (27·50 ft.) to the staff reading at G20 (8·45 ft.)—the level of the distant station is therefore 35·95 ft. less the height of the instrument from the ground at station A. The gradient of station B is got without calculation by reading the staff at that station. If lower gradients than 20 and 25 are used levels up to nearly 100 ft. can be taken.

GRADIENT PAIRS.

$$\left.\begin{matrix}G\ 100\\ G\ \ 50\end{matrix}\right\}\quad\left.\begin{matrix}66\tfrac{2}{3}\\ 40\end{matrix}\right\}\quad\left.\begin{matrix}60\\ 37\tfrac{1}{2}\end{matrix}\right\}\quad\left.\begin{matrix}50\\ 33\tfrac{1}{3}\end{matrix}\right\}\quad\left.\begin{matrix}33\tfrac{1}{3}\\ 25\end{matrix}\right\}$$

$$\left.\begin{matrix}25\\ 20\end{matrix}\right\}\quad\left.\begin{matrix}20\\ 16\tfrac{2}{3}\end{matrix}\right\}\quad\left.\begin{matrix}12\tfrac{1}{2}\\ 11\tfrac{1}{9}\end{matrix}\right\}\quad\left.\begin{matrix}11\tfrac{1}{9}\\ 10\end{matrix}\right\}$$

Any pair of these gradients being used the difference of their staff readings gives the linear horizontal distance.

The rule that "any gradient and its half being used, it gives the higher figure as multiplier for the difference of the two readings"—the horizontal distance being thus given, is useful to remember.

Thus $\left.\begin{matrix}G\ 80\\ G\ 40\end{matrix}\right\}$ gives 80 "multiplier." $\left.\begin{matrix}70\\ 35\end{matrix}\right\}$ gives 70 "multiplier."

$\left.\begin{matrix}60\\ 30\end{matrix}\right\}$ gives 60 "multiplier." $\left.\begin{matrix}50\\ 25\end{matrix}\right\}$ gives 50 "multiplier."

$\left.\begin{matrix}40\\ 20\end{matrix}\right\}$ gives 40 "multiplier." $\left.\begin{matrix}30\\ 15\end{matrix}\right\}$ gives 30 "multiplier."

$\left.\begin{matrix}20\\ 10\end{matrix}\right\}$ gives 20 "multiplier."

The explanation of this rule is as follows:—Let G 40 and its half G 20 be taken as examples. Assume the staff reading at G 40 to be 13·86 ft., and the reading at G 20 to be 8·45 ft.—the difference of these readings would be 8·45 ft., this amount multiplied by the higher figure G 80 gives 432·80 ft., thus:—

$$\begin{array}{r}5{\cdot}41\\ 80\\ \hline 432{\cdot}80\text{ ft.}\end{array}$$

and the horizontal distance from the instrument to the staff is, in this case, 432·80 ft.

It will be seen on inspection that the reading at G 80 gives a vertical depth from the horizontal line of $\frac{1}{80}$th part the horizontal distance, and in a like manner the reading at G 40 gives a vertical depth of $\frac{1}{40}$th (or $\frac{2}{80}$ths) of the horizontal distance; their difference will necessarily be $\frac{1}{80}$th of the horizontal distance, and, the higher figure 80 being used as a "multiplier" will give the resulting distance as 432·80 ft.

The application in this example is that $\frac{1}{40} = \frac{2}{80}$ths, and the difference $\frac{1}{80}$ requires 80 as a "multiplier" to resume the full horizontal distance 432·80 ft.

Again, setting-out distances with Short's gradient-telemeter level can be applied by the subtense method, by use of the following rule :—If any two integers whatever be taken, and used as divisors into the distance required, the result will be a gradient-pair which, on being worked with, will give on the levelling staff a subtense in feet that is equal to the difference between the two integers selected.

Example :—(Selecting integers 5 and 10)—for distance 315 ft.

Distance 315 ÷ integer 5 = 63
" 315 ÷ " 10 = 31½

difference = 5 giving subtense 5 ft.

Method of work, working with gradients 63 and 31½ :—Set up the instrument as usual, and send out the levelling staff in the direction of the required line.—Move the index of the instrument to G 63 and read the staff, assume this reading to be 5·86 ft., then, move the index forward to G 31½ and again read the staff. If the distance from instrument to the staff is exactly 315 ft. the second staff reading will be 0·86 ft.—*i.e.*, give difference 5·00 ft. between the two readings. If this second reading is more or less than 0·86 ft. the staff must be signalled farther or nearer, until the difference of the two readings is exactly 5 ft.

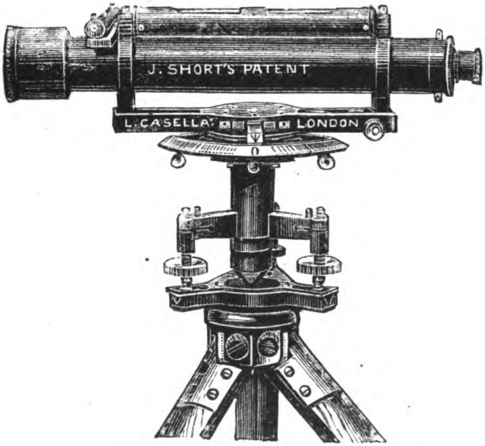
The instrument has a telescope 11 in. long, with an extra large object-glass $1\frac{7}{10}$ in. diameter. This through giving so much light enables the short levelling staves used in mines to be easily read, and by means of the powerful telescope and the graduated arc, the above-ground work incidental to mining engineering can be connected accurately with the setting out of the headways and galleries below, as well as with any additional shafts, &c.

The graduated arc for horizontal angles before named comes in with advantage, as it enables continuous traverses being run, while it measures distances at each separate observation of the traverse.

CHAPTER XX.

LEVELLING INSTRUMENTS AS TELEMETERS.

Short's Gradient-Telemeter Dumpy Level.—This telemeter consists of a telescope fixed on a stage, with a vertical axis working in a parallel plate base, or a locking-plate system with three levelling screws, as may be preferred.

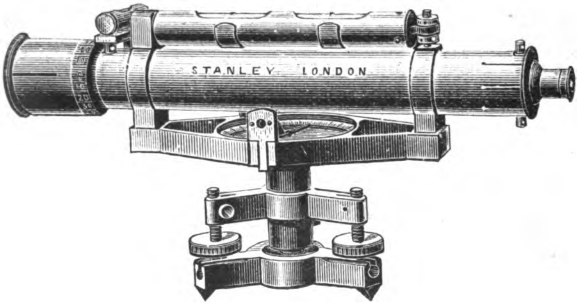


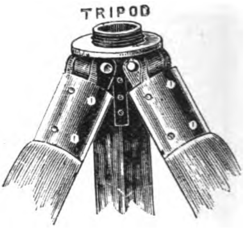
The horizontal limb or circle immediately below the stage has engraved upon it a series of gradients both of rise and fall from 1 in 500 to 1 in 40. This gradient circle is read by an index with a single arrow-point—no vernier being required—and on the index being set at zero the instrument is simply an ordinary dumpy level, and can be used for all the purposes of a level in the usual manner.

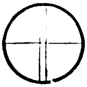
All distances obtained with this instrument are horizontal linear measures, whether measured on slopes or level ground, thus saving the labour and possible errors in reducing slope distances to horizontal linear measurement.

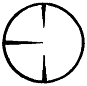
The gradient-telemeter dumpy level has a telescope 12 in. long, with a powerful $1\frac{7}{10}$ in. object glass, capable of reading a staff to ·01 ft. at a distance of 300 or 400 ft.

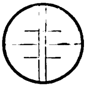
Stanley's Model Level claims the following improvements:—A rigid stand, the top of the head being in one casting, and not built up. A tribrach stage, instead of four parallel screws, which permits the instrument being used on a wall without the legs, prevents all possibility of straining the centre, and allows of the employment of an extra sensitive bubble. In his new telemetrical theodolite patent, this tribrach stage permits a theodolite being used on a wall without the legs. Instead of webs, which may be a constant expense and anxiety to the engineer or surveyor, platinum iridium points are substituted. These neither

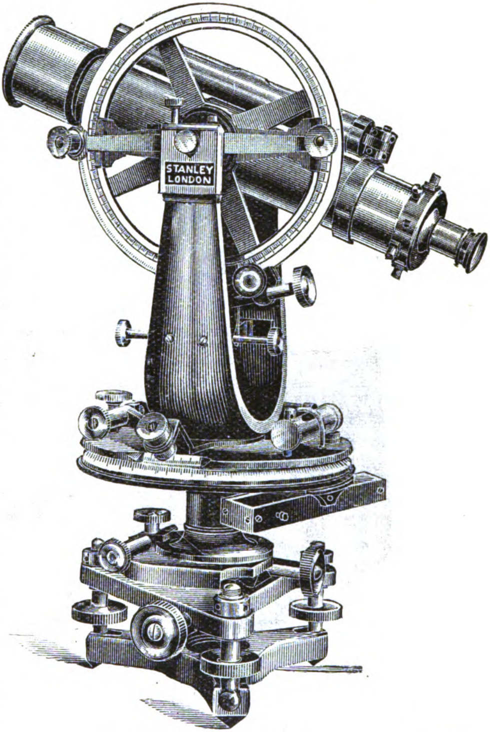




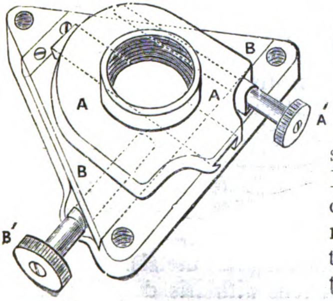

Webs.

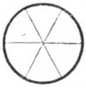

Platinum iridium Stadia Points.


Glass Stadia diaphragm.

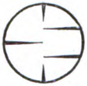


rust nor break, are permanent in all climates, and allow of any dust being brushed off with a camel hair pencil, without interfering with the adjustment. The cap of the telescope is sighted and divided to 30° for taking rough inclines, and the instruments are larger than corresponding sizes of the ordinary pattern, the size being measured from the object-glass to the diaphragm only, instead of including the eye-piece, as customary in the trade. The object-glass is worked with great care to secure light. The instrument which forms the theodolite has a mechanical stage (see details in small engraving, A B) for shifting the centre with exactness over the desired spot: the A′ screw head moves the A plate, and the B′ screw head the B plate. The telescope supports and the centre are in one casting, also the

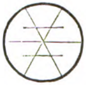




Webs.



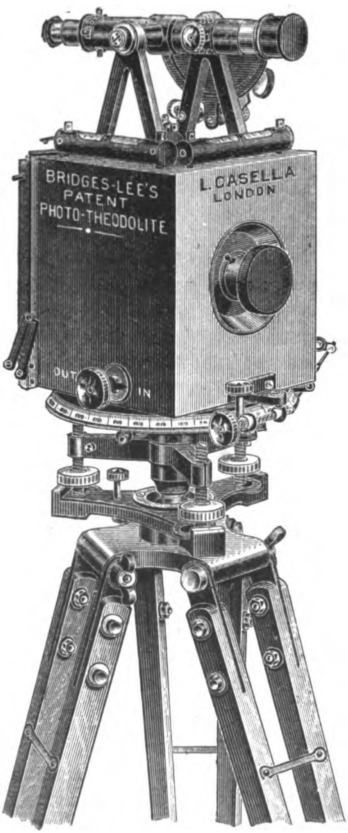
Platinum-iridium Stadia Points.



Glass Stadia diaphragm.

size of the bearing on the centre has been increased. The eyepiece is also fitted with two vertical adjustable points for measuring distances. A long trough needle is supplied with each instrument in place of the usual small circular compass.

New Photo-Theodolite, designed by Mr. J. Bridges-Lee, M.A., F.G.S., &c. —The instrument has been specially designed to give true photographic perspectives, always in a vertical plane and at constant distance, and it is furnished with specially designed mechanism inside the camera for recording on the negative all or nearly all the information necessary for interpreting the picture.



The practical advantages which result from having necessary data for interpretation recorded on the face of the picture instead of in separate note books are very great. Risks of error and confusion are very much reduced. Much time is saved both in the field and in office. Plotting operations are rendered more easy, certain, and accurate, and the pictures will be more valuable as permanent records for future reference. The instrument consists of :—

(1) A rectangular box of aluminium (cast metal).
(2) A rectilinear photographic lens with iris diaphragm,

This lens is accurately set in correct position with reference to the other parts of the instrument, and it has no focussing adjustment. For the purpose of fitting the instrument to be used for ordinary photographic work at short distances, a second photographic lens working in a focussing sleeve with rack and pinion adjustment is supplied.

(3) The azimuthal circle, divided to half degrees with vernier attached to the back of the box to read to minutes.

(4) Tribrach locking plates and levelling screws.

(5) Telescope with cross webs in the body and usual adjustments. This telescope is free to rotate only in a vertical plane when the instrument is accurately levelled, and the line of collimation and the vertical web are in the median vertical plane of the instrument—the same plane which bisects the photographic lens and passes through the axis of revolution of the internal magnetic compass and the vertical hair in the camera.

(6) Vertical limb divided to half degrees, moving with the telescope with fixed vernier to read to minutes.

(7) Revolving tubular level let into a socket in the roof of the aluminium box. By the aid of this level the horizontality of the instrument can be adjusted in any position without disturbing the position of the camera.

The "Transactions of the Society of Engineers" for October, 1899, contain a Paper dealing with the improvements effected by Mr. Bridges-Lee in the apparatus employed for photographic surveying.

BONING.—Boning is a description of levelling, which can be performed by foremen or gangers in road, drainage, and railway making. An experienced man, if given a couple of levels at the commencement and termination of a given gradient, will bone the intermediate levels with very great accuracy. Boning is performed with boning rods, which exactly resemble T squares, as shown in fig. 1 (page 265). The use of boning rods in the setting-out of a line of sewer, is shown in fig. 2 for fixing the inclination of an invert. Given a level upon which a boning rod can be held at a point upon the invert or upon the top of a fixed peg, and another point or peg, the level of which is approved for a gradient, any intermediate point can be determined with the use of boning rods of

FIG 2

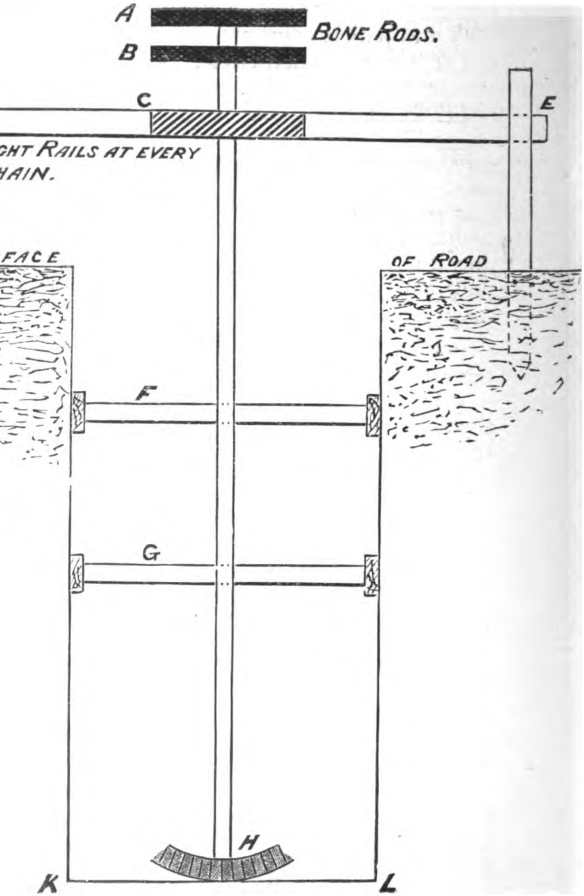
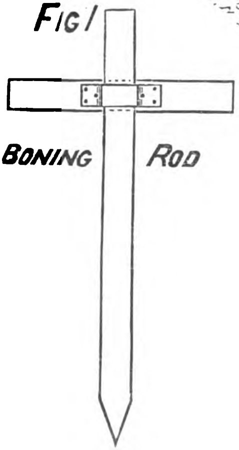


FIG 1



BONING ROD

exactly equal lengths. If the top of the rod B is viewed in line with the top of A and C the line of inclination is correct. If it is above, it must be lowered and the trench cut away to suit. If it is below, the excavation has been made too deep. By adding the space required for the brick invert and concrete foundation to the length of the intermediate rod B, the excavation can thus be approximately checked.

When used for a level line, an ordinary hand level or bricklayer's level should be introduced to level a line over two pegs driven into the ground and adjusted until the tops of the two pegs are at the same level. Then by the aid of boning rods the top of a third peg can be set at the same level either at a convenient distance beyond either of these two pegs or as an intermediate peg.

In both cases care must be taken to hold the boning rods upright. The level employed is a spirit level rather than a water level, on account of the comparative slowness of travel in the former compared with the latter. If a glass or tube be filled with spirits of wine or other spirit, and another with water, it will be found upon pouring the liquid from each by inversion and subsequent examination of each glass, that the one which contained the spirit is less completely emptied than that which contained plain water, and the reason is that the adhesion to the sides of the glass by the spirit could not be instantly overcome by a slight force. Hence a spirit level gives warning for readjustment, and is rendered more manageable than a water level. For ordinary spirit levels, the glass tube is used as it comes from the tube drawer, but for bubble tubes attached to optical instruments they are ground on their inner surface by rubbing them with emery powder and water, on a brass cylinder bent to curve.

CHAPTER XXI.—CURVE RANGER.

Dalrymple-Hay's Curve Ranger is designed to facilitate the operations in the field when ranging curves by the method of tangential angles.

By simple mechanical movements it gives the tangential angle for each chain point in all curves in general use on railways, and thus obviates the necessity of first referring to a table of tangential angles, and then of reading the vernier as with the theodolite.

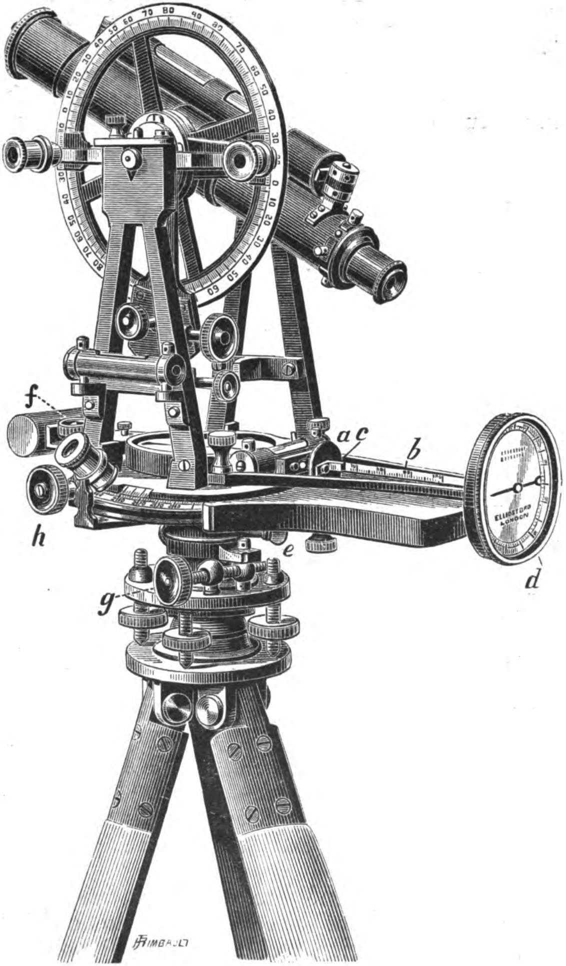
When ranging new tangents no calculations are required.

To the railway engineer, the advantages of this instrument will at once be apparent.

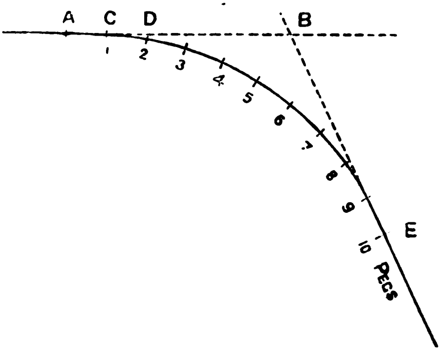
Example.—To set out a curve of 40 chains radius.

	WITH THEODOLITE.		WITH CURVE RANGER.
1.	Set up instrument (these are similar.)	1.	Set up instrument.
2	Set vernier to zero and direct telescope along tangent line, and clamp instrument.	2.	Set steel disc to division 40 on graduated scale.
3.	Look up in table first tangential angle for 40 chain curve =0°.42′.58″.	3.	Direct telescope along tangent line, bring table under same, set needle to zero of dial face, and clamp instrument.
4.	Set vernier to read this angle by turning tangent screw. The telescope will then point to the first peg in the curve.	4.	Bring needle to division 1 on dial by turning tangent screw. The telescope will then point to the first peg in the curve.
5.	Look up in table second tangential angle=1°.25′.56″.	5.	Bring needle to division 2 on dial by turning tangent screw. The telescope will then point to the second peg in the curve.
6.	Set vernier to read this angle by turning tangent screw. The telescope will then point to the second peg in the curve.	6.	Bring needle to division 3 on dial by turning tangent screw. The telescope will then point to the third peg in the curve.

7. Look up in table third tangential angle=2°.8′.54″.
8. Set vernier to read this angle by turning tangent screw. The telescope will then point to the third peg in the curve, and so on.


f
a c
b
h
e
d
g
ELLIOTT BROS LONDON
RIMBAULT

Directions for Use.—Having set up the instrument at the commencement of the curve, move the small steel disc (*a*) along the graduated scale (*b*), until the setting-index (*c*) fixed to the steel disc coincides with the division on the scale corresponding to the number of chains radius in the curve.



Thus, if the curve to be set out is of 80 chains radius, move the steel disc (*a*) along the scale (*b*) until the edge of the setting-index (*c*) is coincident with division marked 80.

Now direct the telescope along the tangent line to the curve, and clamp it by the two clamps (*a*) and (*e*). The bisection of the cross-wires (on the diaphragm) can now be made to coincide with the pole in a required position by the use of a tangent-screw.

The horizontal table should be brought under the wheel (*a*), with which it will then be in contact. Clamp the table (*f*) by the clamp (*g*). (*i*) is a slow motion screw for the horizontal table.

Now set the needle to the zero of the dial (*h*) by turning the thumb-screw (*j*) fixed to the end of the graduated scale (*b*).

If the curve bends to the right, turn the tangent screw (*k*) until the needle points to division 1 on dial. In this position the telescope will point along the chord line, and along this line measure a chord of 1 chain. We thus obtain the first point in a curve of 80 chains radius.

To obtain the second tangential angle, again turn the tangent screw (*k*) in the same direction, until the needle points to division 2 on the dial, the telescope will then have described the second tangential angle, and will point along another chord line. Measure the chord line intersecting the line of sight at the correct distance. This determines the second point, and so on a considerable number of points can easily be set out.

If the curve bends to the left, the needle instead of pointing to 1, 2, 3, &c., should be made to point to 99, 98, 97, &c., divisions on the dial, by turning the tangent screw (*k*) the reverse way.

Ranging a new tangent.—This is equally simple. Suppose it is required to set out a new tangent at, say peg 10. If the needle, when the telescope was pointing to peg 10, from the position of the instrument indicated 10 on the dial face, remove the instrument to peg 10, and there set it up, still pointing in the direction that the curve is being set out.

Take the telescope out of the Y's and reverse it, end for end, See that the table is under the steel disc. Now set the needle to indicate 90 upon the dial, by the thumb screw alluded to above, and turn the telescope horizontally until the needle indicates zero on the dial. Tighten the two clamps controlling the telescope, and perfect the zero reading of the needle on the dial by the tangent screw. The telescope is then taken out of the Y's, and replaced in its original position, when the curve may be continued in either direction to the right or left as described above.

The table and its verniers are divided to read horizontal angles to single minutes. The instrument can be inspected at the works of Messrs. Elliott Brothers, 101, St. Martin's Lane, Charing Cross.

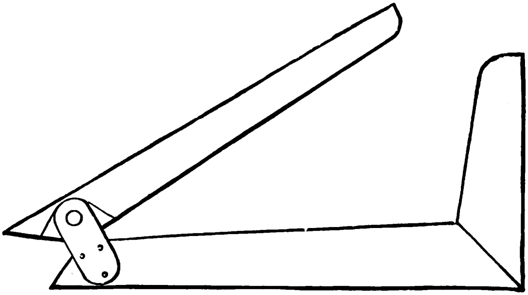
CHAPTER XXII.

THE CLINOGRAPH.

The Clinograph (Harrison's Patent) is a set-square with a swivelling blade, used in conjunction with a T-square, for drawing lines parallel, perpendicular, or symmetrically inclined to any given line or direction.

With one edge of the instrument resting against the edge of the T-square, the blade can be instantly set to the required position, and the friction of the joint is sufficient to hold it firmly while in use.

For drawing parallel lines it is slid along the T-square to any part of the drawing paper. For perpendicular or symmetrical lines, after being set, it is turned with its other edge against the T-square, or with its other face on the paper, as the case may be, after which it is slid into any position as before.



Since one edge always rests against the T-square, the discomfort attending the ordinary methods of drawing inclined lines is avoided, and such work is greatly facilitated, whilst at the same time greater accuracy is secured.

CHAPTER XXIII.

THE ANEROID.

Aneroid Barometers.—The word aneroid is derived, in an anomalous way, from the Greek privative *a* and *neros*, wet. The invention of the aneroid barometer was attributed to Conté in 1798, and to Vidi of Paris, about 1844, and excited much attention in 1848-9.

These ingenious and elegant instruments are most useful to travellers who, moving from place to place, desire in their progress to take reliable notice of meteorological phenomena; whilst the measurement of heights is here obtained by means of a thin, flat, metallic box, which is deeply corrugated to increase its elasticity, and from the interior of which the air has been carefully removed; the upper and lower surfaces of this are held in a state of tension or separation from each other by means of a strong spring; the atmosphere, pressing with varying force on these surfaces, conveys action to smaller springs, and thus show by hands on the dial the variation of heights, or changes of the weather. In the measurement of small differences of height, as well as great elevations, the improved aneroid is most valuable; not only does it show with precision the differences in height between one room and another, or the varying gradients in travelling on a railway, but it is now so improved as to show with precision elevations up to 24,000 feet. They are now made of pocket size, but besides portability, the aneroid has another great advantage over a mercurial barometer, namely, that it is possible so to construct it as to be independent of any correction for temperature of the instrument.

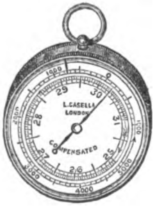
An aneroid barometer is made with greatly expanded graduations, the circle divided to ·02 inch, from 28 to 31 inches, by which an extraordinary degree of sensitiveness is produced.

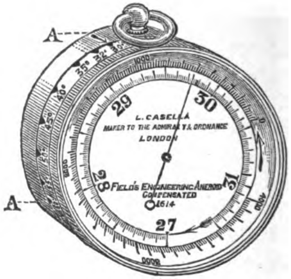
An aneroid barometer is also made, extra small in silver case, with double back, 1⅝ diameter, for measuring heights up to about 6,000 to 19,000 feet.

Aneroid barometers (Field's engineering) are also sold watch size, nickel plated, especially adapted for preliminary surveys of low levels.

A scale of altitudes usually accompanies any of the above instruments gratis, or may be engraved on their dials.

One of the chief uses of aneroid barometers is for measuring differences of elevation by means of the diminution which takes place in the atmospheric pressure as we ascend to a higher level. This diminution is not equal for equal differences of altitude, in consequence of the elasticity of the air, which allows the lower strata to be pressed more closely together than those above them; but it follows known laws, and hence altitude scales have been computed, taking the varying ratio between pressure and altitude into account.




A
A
L. CASELLA
MAKER TO THE ADMIRALTY & ORDNANCE
LONDON
FIELD'S ENGINEERING ANEROID
COMPENSATED
1614
29
30
31
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There is, however, a second cause of variation, which (though included in the recognised formulæ for reducing barometrical determinations of altitude) has not been included in any altitude scale yet published. This cause is the variable temperature of the air, which will evidently affect the result by affecting the density of the air, and therefore the ratio of pressure to altitude. In the "Engineering Aneroid," invented by Mr. Rogers Field, B.A., Assoc.Inst.C.E., F.M.S. (of which L. Casella is appointed sole maker), this variation is for the first time taken into account by the scale being made adjustable for temperature.

The principle of adjustment is that of shifting the altitude scale according to the temperature of the air. There is nothing novel in movable scales themselves, as they are frequently used with aneroids for the purpose of shifting the zero of the scale to correspond with the varying position of the hand. This method of using them is, however, radically wrong, as the shifting of the scale makes it inaccurate, and the novelty consists in taking advantage of this inaccuracy to obtain a valuable means of adjustment.

The temperature of the air is applied by shifting the scale in accordance with the figures engraved on the outside of the instrument. The rim which holds the glass should be slightly raised, so as to be free from the locking-pin, and then turned until the figures corresponding to the air temperature are opposite to the pin, when the glass should be depressed so as to re-lock it.

The process of observation is extremely simple. The first thing is to determine, either by observation or estimation, the air temperature likely to prevail during the series of observations; if this is done within 5° it will be sufficiently accurate (within about 1 per cent). The scale must then be set to this temperature in the manner above explained. Subsequently the readings must be taken from the outer scale of feet, and the difference will give the difference of elevation. The following example of actual observations taken between Hampstead and London will explain the proceeding:—

Temperature of 40° *and scale set accordingly.*

JOURNEY TO LONDON :—	FEET.	
Reading at Jack Straw's Castle, Hampstead	1640	
Reading at "Horse Guards," London	1200	
Difference ...		440
JOURNEY FROM LONDON :—		
Reading at "Horse Guards," London	1215	
,, ,, Jack Straw's Castle, Hampstead	1640	
Difference ...		425
		2)865
		432 ft.

The true difference of altitude, according to the Ordnance levels, is 428 feet showing an error of only 4 feet. The accuracy of the result will be further increased if the observations are repeated more than once, and the average of the results taken.

It should be mentioned that the above principle oi adjustment can only be correctly applied to aneroids in which the graduation is nearly uniform, and therefore extreme care should be taken in the selection of suitable instruments for this purpose.

The aneroid barometer may be depended upon when the two readings can be taken within such a short time of one another so that the instrument is not likely to have been affected by the changes of pressure. It may be found useful in sketching mountains during settled weather when no great fluctuations of atmosphere are to be expected. It is the facility of reading the records that gives to the aneroid an advantage over a mercurial barometer. The mercury is not flat, but bulges and curves upwards when rising and falling, while in an aneroid the readings are aided by a needle point register attached to a moveable rim, which can be brought point to point against the index and the needle point travelling nearly in contact with the foot of the divisions, the slightest movement that human vision can detect is apparent. Its results, however, are mainly dependent upon the accuracy of the mechanism by which it represents the movements of a mercurial barometer, and, as the elastic property of the metal varies, it should be regulated by occasional comparison with the primary instrument.

We have now provided our readers with an account of the principal instruments employed in the field for surveying and levelling, and such as we trust may enable the student to properly handle and use the same. For further instruction respecting their application, as well as for a description of the office work connected with a survey, we must refer our readers to the companion volume entitled "Land Surveying and Levelling."

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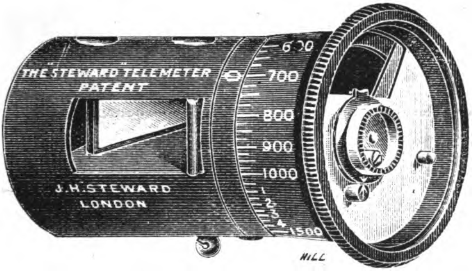

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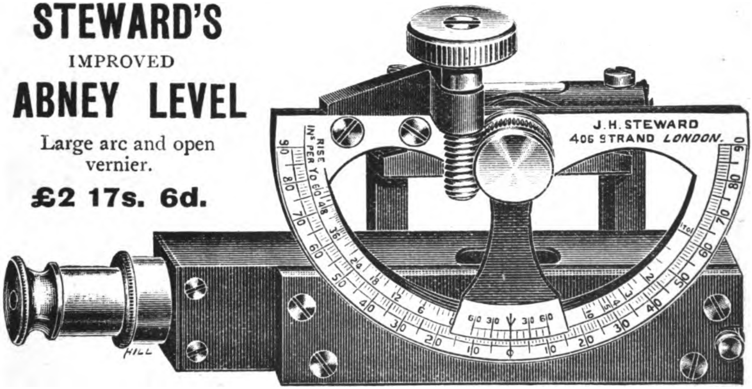

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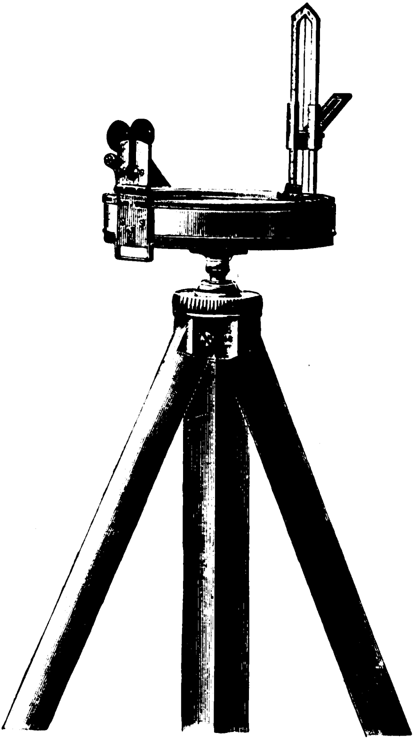

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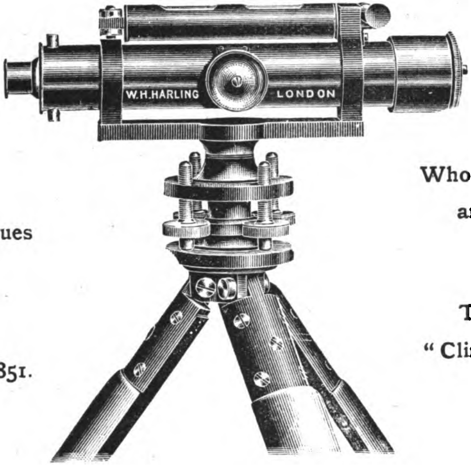

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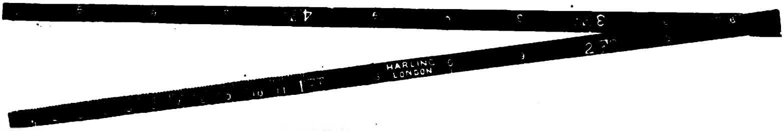

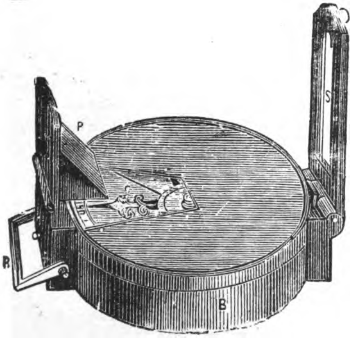

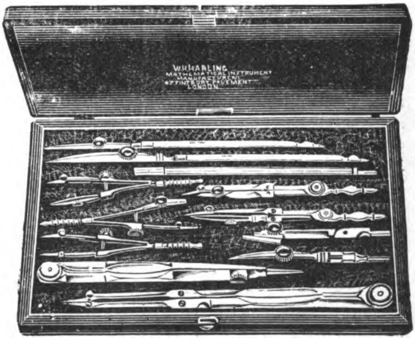

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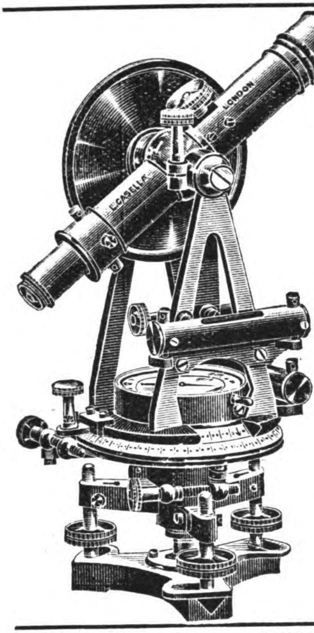

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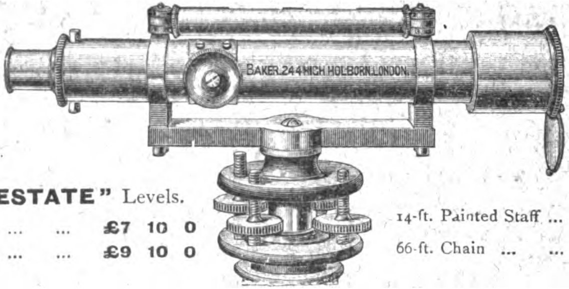
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